The SCIENTIFIC MONTHLY

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CONTENTS

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THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

Founding and Organization

In 1848, on September 20, the Association was formally organized and held its first meeting; in 1874 it was incorporated under the laws of the Commonwealth of Massachusetts and given the right to receive, purchase, hold and convey property. Its governing body is a Council, now having 255 members.

The Association is national in scope, with membership open to the whole world on equal terms, and its interests include the broad fields of the natural and the social sciences. Its varied activities are carried on under 16 sections with which 189 affiliated and associated societies, having a combined membership of nearly a million, cooperate in organizing programs for its meetings.

Members and Meetings

All persons engaged in scientific work, all who find pleasure in following scientific discoveries, all who believe that through the natural and social sciences a better society may be achieved are eligible for membership in the Association. From its founding, the most distinguished of American scientists, including every American Nobel Laureate in science and every president of the National Academy of Sciences, have been members. The names of many university presidents, of eminent scholars in widely different fields, and of men notable for public service, including a United States Senator, a Justice of the Supreme Court, and a former president of the United States, are now on its roll of more than 25,000 members.

The Association's meetings are field days of science attended by thousands of participants at which hundreds of scientists vie with one another for the pleasure and the honor of presenting results of researches of the greatest benefit to their fellow men. An enlightened daily press reports their proceedings throughout the country.

Opportunity and Responsibility

A world torn by conflicts and fearful of the future is looking more and more toward scientists for leadership. The opportunity for unparalleled service is theirs and the fact that they have available the only essentially new methods, if not purposes, imposes an equal responsibility. For these reasons it will be the Association's steadfast purpose to promote closer relations among the natural and the social scientists, and between all scientists and other persons with similar aspirations, to the end that they together may discover means of attaining an orderliness in human relations comparable to that which they find in the natural world about them.

MEET THE AUTHORS

THOMAS CHROWDER CHAMBERLIN, Ph.D., Sc.D., LL.D., once professor in Beloit College, later President of the University of Wisconsin, a position he resigned in 1893 to become the first Head of the Department of Geology in the infant University of Chicago, in 1897 published the article reprinted in this issue of the MONTHLY. He was a large man physically, a great man intellectually, a noble man morally. He came from an honest, industrious, and wholesome family. He grew up on the early Illinois prairies, he spent his late boyhood among the glacial moraines in Wisconsin, he ranked in his mature manhood with the foremost scientists in the world.

The life and accomplishments of Chamberlin pose interesting, and apparently insoluble, questions regarding the effects of heredity and environment. Hundreds of thousands of young men from good families grew to manhood on the prairies and among the lakes of Wisconsin, but no other one traced out so skillfully the meaning of terminal moraines, or questioned so searchingly and persistently the causes of their appearance and disappearance, or was led finally back across the geological ages to the origin of the earth and the other members of the solar family. With imagination, daring, industry, and genius, he used, as well as advocated, the Method of Multiple Working Hypotheses in developing the Planetesimal Hypothesis of the origin of the planets which revolve around the sun, with all its collateral riches respecting the organization and interrelations of the tens of billions of suns that constitute the Milky Way System. These bold adventures into time and space marked the beginning of a revolution in theories of cosmogony comparable to that which followed the work of Copernicus.

Chamberlin wrote many papers and books, all of which he did with the meticulous care and thoroughness with which he traced out the courses of continental glaciers. He questioned everything, however solidly it was thought to have been established; he followed every clue to new interpretations, however faint it may have been; he discarded every opinion proved erroneous, however dearly it may have been held. In him the naturalist and the philosopher were combined.

In demeanor Chamberlin was always dignified but not austere. To all he was courteous and gracious but never condescending. With his colleagues and students he was friendly, sometimes jovial, without ever being hilarious. Even in his lighter moments he always gave the impression that strong currents were flowing far beneath the surface. Nothing delighted him more than informal discussion with congenial spirits on cosmogony and evolution.

NEW BOOKS*

You Are Younger Than You Think. MARTIN GUMPERT. 244 pp. 1944. $2.75. Duell, Sloan & Pearce, Inc.

This informative and encouraging book is written for senescent people who want to know what to do, or what can be done, to defer incapacity and senility and to grow old gracefully. Written by a physician, it is not only helpful, but interesting.

Men of Science in America. BERNARD JAFFE. 600 pp. Illus. 1944. $3.75. Simon and Schuster.

The story of science in America is built up around the life and work of twenty American scientists and their contemporaries, beginning with Thomas Harriot (1560–1621) and ending with E. O. Lawrence of cyclotron fame. This has the earmarks of an intensely interesting and informative book.

Climate and the Energy of Nations. S. F. MARKHAM. 236 pp. Illus. 1944. $3.50. Oxford University Press.

One needs no statistician to tell him that climate has an effect on human energy and accomplishment. What that effect may have been in the past and what it may be in the future throughout the world is described in this thorough and entertaining study.

They Hop and Crawl. PERCY A. MORRIS. 253 pp. Illus. 1944. $3.50. Jaques Cattell Press.

It is doubtful that books on reptiles and amphibians can compete with those on birds and insects; but the former have a creepy fascination exemplified by the present well-illustrated book, which is good for the timid armchair naturalist and the hardier nature lover.

Ourselves Unborn. GEORGE W. CORNER. 188 pp. Illus. 1944. $3.00. Yale University Press.

Those who have read Dr. Corner's book on hormones in human reproduction will want to read the present book in order to be brought up to date on knowledge of human embryology. Dr. Corner has an ability to write for laymen in a manner that a professional science writer might envy.

Guide to Higher Aquarium Animals. EDWARD T. BOARDMAN. 107 pp. Illus. 1944. $2.00. Cranbrook Institute of Science.

Any person who thinks that goldfish are the only animals that can be kept in an aquarium will be amazed to find in this book that many native fishes, frogs, salamanders, snakes, and turtles can also be caused to live happily in a tank of water containing the proper plants and food.

Social Darwinism in American Thought 1860–1915. RICHARD HOFSTADTER. 191 pp. 1944. $2.50. University of Pennsylvania Press.

This scholarly book traces the effects of Darwin's hypotheses on social thought and action. In the past many a rugged individualist resorted knowingly or unknowingly to Darwinism to rationalize or justify his faith in the efficacy of unrestricted competition.

*** Orders for the books noticed above should not be sent to THE SCIENTIFIC MONTHLY or the A.A.A.S., but to your bookseller or the publisher.**

MEET THE AUTHORS, Continued

JOHN F. EMBREE, Ph.D., is now in charge of area work in the Far East Civil Affairs School at the University of Chicago; in other words, he is engaged in training A.M.G. officers for Japan. He was born in New Haven, Conn., in 1908, took his undergraduate work at the University of Hawaii, and his graduate work in anthropology at the University of Toronto and the University of Chicago. He prepared himself for his present duties by traveling extensively in eastern Asia and Malaysia, and he has published a number of studies of Japanese social organization, including *Suye Mura, A Japanese Village* (1939), and Smithsonian War Background Study No. 7, *The Japanese* (1943). Before the war Dr. Embree taught at the University of Toronto. Since Pearl Harbor and before taking his present position, he worked successively for the Office of Strategic Services and the War Relocation Authority.

KARL P. SCHMIDT, A.B., is Chief Curator of Zoology at the Chicago Natural History Museum (formerly the Field Museum). He was born in Lake Forest, Ill., in 1890 and became a first-class naturalist at Cornell University, taking extensive collecting trips while still an undergraduate. Since he graduated in 1916 and entered museum work, he has traveled repeatedly to foreign fields, especially to Central and South America and the Pacific Islands. Mr. Schmidt is president of the American Society of Ichthyologists and Herpetologists and is herpetological editor of the society's journal, *Copeia*. He is section editor for amphibians and reptiles of *Biological Abstracts*. Mr. Schmidt is an excellent writer of verse and prose. Later THE SCIENTIFIC MONTHLY will publish an account of his trip to Peru in 1939. In addition to technical reports on reptiles and amphibians, he has written books on natural history for children. His present poem is dedicated to James Hutton (1726–1797), "a private gentleman" of Edinburgh who announced the principle of uniformitarianism.

MEET THE AUTHORS, Continued

JOEL W. HEDGPETH, A.M., is a biologist who has become a free-lance writer. Born in Oakland, Calif., in 1911, he graduated from the University of California in the depths of the depression. After working at several dismal jobs, he was rescued to participate in a biological survey of California rivers, studying the problem of dams versus salmon. In his present article he pleads the cause of salmon against the dam builders. Being convinced that natural resources are more important than certain engineering projects, he has formed a Society for the Prevention of Progress, a rather startling title, which calls attention to the fact that not all forms of so-called progress are desirable. Mr. Hedgpeth is the proud father of two books that have not yet found a publisher, and he is now working on a popular history of oceanography. His address is Box 911, Walnut Creek, California, near San Francisco.

HARVEY C. LEHMAN, Ph.D., is Professor of Psychology at Ohio University. He wants it understood that Ohio University is located at Athens, Ohio, and not at Columbus, which is the seat of The Ohio State University. Professor Lehman was born near Humboldt, Kansas, in 1889. All his college work up to his master's degree was done at the University of Kansas. He took his Ph.D. at the University of Chicago. During World War I he was a corporal in the Coast Artillery. Prior to 1927 when he went to Ohio University, he taught psychology in Minnesota and Kansas. Professor Lehman is not a newcomer to THE SCIENTIFIC MONTHLY, having published six articles previously in the MONTHLY and many more elsewhere. His earlier publications dealt with the psychology of play and recreation. More recently he has been publishing studies which deal with the chronological ages at which men have become champions in athletics, art, literature, science, invention, and the like; also the ages at which men become topnotch leaders in commerce, politics, war, religion.

MEET THE AUTHORS, Continued

Denis Llewellyn Fox, Ph.D., is Associate Professor of Marine Biochemistry at the Scripps Institution of Oceanography (University of California), La Jolla, Calif. He was born at Udimore (near the ancient Cinque Port of Rye), Sussex County, England, in 1901. His parents took him to California in 1905, and his father soon became a naturalized citizen. After Dr. Fox graduated from the University of California at Berkeley, he became a chemist in the Research and Development Department, Standard Oil Company of California. In 1929 he resigned that position to undertake advanced study in biochemistry at Stanford, where he received his Ph.D. in 1931. He then began his career at the Scripps Institution, leaving it only during 1938–1939 to continue his studies of plant and animal pigments at the University of Cambridge under a research fellowship of the Rockefeller Foundation. His research has been concerned with comparative biochemistry and physiology, and with chemical and physical interrelationships between marine organisms and their environment, with special reference to the occurrence, distribution, and biochemistry of plant and animal pigments. His wartime research has been devoted to studies of marine fouling organisms and chemical methods of inhibiting their attachment. Unlike that of most chemists, whose biological knowledge is notoriously scanty, Dr. Fox's principal hobby is natural history in the field and the study and care of animals in the zoo.

J. O. Perrine, Ph.D., is Assistant Vice-President of the American Telephone and Telegraph Company, New York City. His article on radiations and his biographical sketch were published in the issue of January, 1944.

Stephen S. Visher, Ph.D., is Professor of Geography at Indiana University. This is his third paper in the 1944 Monthly on the weather. See the May issue for his biographical sketch.

S. J. Holmes, Ph.D., LL.D., is Professor Emeritus of Zoology in the University of California at Berkeley. The first part of his present article appeared in the September issue together with his biographical sketch. The four parts of the article will be assembled in one reprint, which can be obtained from Professor Holmes.

THE SCIENTIFIC MONTHLY

NOVEMBER, 1944

CRYSTAL QUARTZ: MECHANICAL ALLY OF ELECTRICITY

By J. O. PERRINE

ELECTRICITY in its own right is not a useful commodity in everyday life. Charges of electricity, be they positive or negative, be they at rest or in motion, be they associated with matter or in their stark selves as electrons, are after all not much good per se in the welter of life. Rather it is the amazing capacity of electricity to enter into entangling alliances with various forms of power that makes it the greatest servant of mankind. On the other hand, air and water as such are vital necessities in the sheer fact of human existence. They, being more versatile than electricity, also play an important role in their embodiment and transmission of mechanical power for the world's work. Electricity has but a single task in life's affairs— to act as the number one intermediary and top ranking entrepreneur in the universal relations of heat, light, sound, mechanics, and chemistry.

Electricity is present at all times and in all things. It is here, there, and everywhere. Every substance and every object in the universe consists of an incomprehensibly vast and turbulent array of electrical charges—now called "electrons." Like the planets rotating about the sun, these tiny, invisible, and imponderable particles of pure electricity whirl without and within atomic nuclei. Electrical charges, negative and positive—electrons and protons—are the stuff out of which matter is made: a daffodil, a steel rod, a copper wire, a grain of wheat.

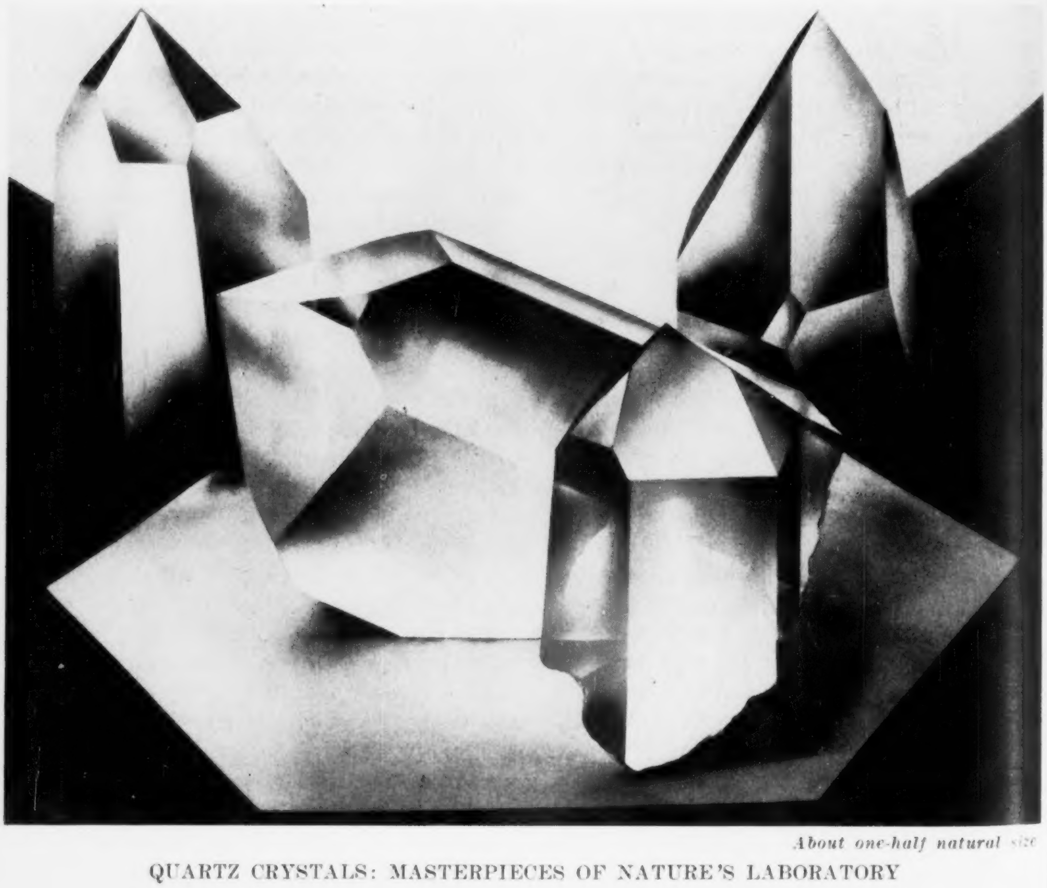
The problem of the scientist and the engineer has ever been to find out how to enlist the co-operation of electricity to do the job at hand. During the seventeenth century charges of high intensity which severely shocked animals and humans seemed to indicate that the only possible use of electricity was in the field of medicine. On one occasion in those olden times, 2,500 persons in a hand-to-hand line one mile long were shocked by a so-called static electricity machine. About 1776 an electric charge from such a machine was sent thirty miles across the Lombardian Plains of Italy to give a spark by which inflammable gases in Milan were exploded. In these manifestations of electricity, the charges were produced by friction; at least, that was the contemporaneous explanation of why things happened as they did. Sulphur, glass, and amber were vigorously rubbed by silk, furs, and woolen cloths in hand or by crude mechanisms to produce electrical charges of great severity. Today brisk scuffing of shoes on carpeted floors develops startling shocks when a metal doorknob is grasped. As it appears now, the sheer fact of friction has nothing to do with the basic phenomenon; the pressure involved in the tight rubbing is a means of making intimate contact between the two different substances. The electrical charges that exist in all substances, or it might better be said, the electrical charges out of which the atoms and molecules of all substances are made, are a restless and unhappy lot. Like the animal which thinks the grass over the fence is a bit greener than that of his own pasture, so the charges of electricity, the electrons in one substance, seem to have a disposition to go across boundaries and mix into another kind of stuff with which they are in contact. Electrons in one substance are in a terrific state of random unrest within that substance and are not at all in serene equilibrium with

electrons in other substances. There is a state of unbalance something like the unbalance of the atoms of salt and sugar in water. These substances dissolve of their own accord in water. They do so because of a solution tension, a driving force something like osmotic pressure. We do not know just why, except to say that a state of nonequilibrium seems to be quite the vogue in such matters.

Electric Alliances

Electricity and Chemistry. Up to about the year 1800, therefore, electricity was not a very proficient agency in life's affairs, nor did it give much promise of becoming a useful tool of industry. One day, observations of the twitchings of a frog's leg by an Italian physiologist, Galvani, while working with scalpel and salt solution, suggested to his mind that the cause of the twitchings was electrical. There were no great blocks of sulphur and plates of glass and frictional machines to produce highly intense electrical charges in this case. The physiology laboratory became an electrical laboratory. The twitching of the frog's leg, which could be readily repeated without danger to the experimenter, indicated electrical phenomena of an entirely new variety.

So the first entangling alliance of electricity which gave promise of utility was an alliance between the electrons in metals and the electrons in a salt solution. As before in the contact of silk and glass, so the electrons in a metal in contact with a salt solution are not in balance, are not in equilibrium. There is an inherent electronic tension which drives electrons out of one into the other. Galvani's experiments were soon followed by those of Alessandro Volta who made the first electric battery, a series of copper and zinc plates interwoven by sheets of paper moistened with salt solution. Electricity was no longer a violent, intense, cruel,



About one-half natural size

QUARTZ CRYSTALS: MASTERPIECES OF NATURE'S LABORATORY

QUARTZ CUT INTO VARIOUS SHAPES

whimsical, useless agency. In the voltaic battery, electricity was tamed, serene, controlled, and amenable to do work, to do something useful.

Electricity Goes to Work. Perhaps the first task for an electric battery was the operation of the telegraph in 1844. The one-hundredth anniversary of that event was celebrated a few months ago. The electrical power embodied in the battery could be released by closing a key in a circuit. The electrical power sped with incredible swiftness along a wire and gave up its strength to operate a telegraph receiver. A click or a mark on a piece of paper served as a code for the transmission of information. The great epochal fact was that electricity had become a useful tool, a doer in the world's work. Many batteries with various chemical make-ups for all sorts of uses translate chemical energy to electrical energy and finally to light, heat, or motion in some desired endeavor. Storage batteries, which do not store electricity but which by chemical means store power in electrochemical form, serve today in automobiles, telegraph and telephone systems and give up their power to the assigned task.

It is important at this stage of the discussion to point out that in the alliance of electricity and chemical solution no motion is involved. A battery has no moving parts; no mechanics is involved in a voltaic cell in so far as it is a source of electrical power.

Several important and relevant ideas remain to be considered before the mechanical alliance of crystal quartz and electricity is presented.

Electromagnetic Induction. Electricity became an agent to translate power in enormous amounts by the discovery of the principle of electromagnetic induction. Here chemistry and electron solution tensions play no role whatever, but mechanical power

becomes the source of electrical power. In small and giant electric generators, the electrons inherently present and readily movable in copper wires are displaced in those wires by the sheer fact that the wires move with respect to a magnet. Why magnetic fields, those invisible and intangible auras about a magnet, impel the electrons in nearby wires to bestir themselves is not easy to understand. The basic facts of electromagnetic induction discovered over a hundred years ago by Oersted, Ampère, Faraday, and others are just as difficult to rationalize as is the voltaic battery. Suffice it to say that millions and millions of kilowatt-hours of work are done each day throughout the world by the transformation of the power in coal, in oil, and falling water to electrical power and back again to heat, light, and mechanical jobs of wide variety.

It is significant to observe that in electrical generators and motors motion is involved, and the principal item at issue is work, sheer work, hard work of some kind or other.

Dynamic Microphones and Loudspeakers. In translating the mechanical power of the vibratory motion in the sound waves of speech and music, it is important to note that the electromagnetic inductive technique is also extensively used in communication systems. In microphones, such as shown in Figure 1, the eighty or so turns of fine wire comprising the moving coil, or armature, weigh a tiny fraction of an ounce. The very thin dome-shaped diaphragm upon which sound waves pound with Lilliputian blows makes the coil move in a tiny crevice across which is a strong magnetic field. Electric currents are thus developed in the coil which are facsimiles of the sound waves. To be sure, if electric currents from another microphone and amplifier embodying speech and music are sent into the coil, this same structure becomes an electric motor; more specifically, a loud-speaker. In these cases, millivolts and milliwatts are needed to engineer the job instead of kilovolts and kilowatts. It is interesting that the principle of electromagnetic induction is a two-edged sword and is used for two such widely different objectives in power engineering and communication engineering. In the former, great amounts of power are reciprocally translated by the same philosophy as are the tiny amounts of power of the latter.

Thermoelectric Power. The heat energy

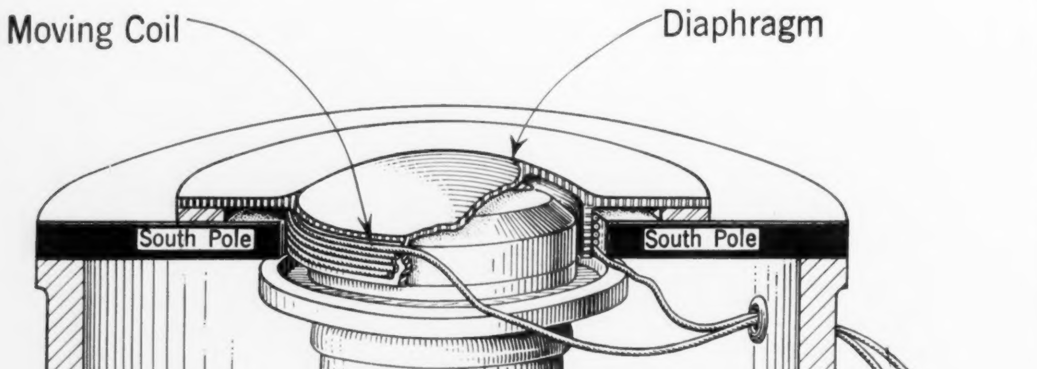


FIG. 1. MOVING COIL MICROPHONE

of coal eventually becomes electrical energy through the medium of steam and electromagnetism. Chemical energy is changed to electrical energy in the many types of batteries. In the voltaic battery the mere contact of two substances gives rise to migration of electrons from one substance to another. Still another interesting and basic alliance of electricity is the direct and primary interchange of heat and electric energy. If a piece of copper and a piece of iron are twisted together, this same sort of migration takes place, but not very intensively. However, if heat is applied to that juncture, the turbulence is increased, and the migration is aided and abetted. In other words, the energy of heat is directly translated to electric energy. If the other ends of the wires are connected to a system capable of using electric power, then one has a different, an entirely different, kind of electric generator —not an electromagnetic, but a pyroelectric, generator. As long as a flame or heat in any form gives its energy to the junction of two metals, heat energy is directly changed to electric energy, and that electrical energy can be changed back to some other form of power.

The amounts of energy involved in this system, basically different from the two previously presented, are always very small. The thermoelectric effect, or pyroelectric effect, would provide a very weak and also inefficient power translation system. Even if the sheer amount of power is not sizable, the phenomenon itself is very valuable in industry. A juncture of dissimilar metals becomes an electric thermometer. If the relation between temperature and intensity of charge, or voltage, is known, then temperatures in remote and generally inaccessible places can be readily determined. In great and intensely hot furnaces, the electric pyrometer is a valuable tool, not to provide power but to reveal temperature. As a matter of fact, the pyroelectric phenomenon is present in a single metal or crystal. If there is temperature difference between different sections of the same object, then an electrical tension, or voltage, exists between those different sections. As in the first alliance, no physical motion is involved in pyroelectricity.

Photoelectricity. Nature always seems to do things reciprocally. Chemical systems provide electrical systems, and electrical systems supply beautiful layers of silver from silver solutions on cutlery and silverware of various kinds. Tons and tons of aluminum are nowadays obtained from solution by electric deposition. In electrodynamic systems, motion drives electricity through wires, and electricity in wires produces motion. Sound power can be changed with great fidelity to electric power in sensitive microphones on the one hand, and, conversely, electric power supplied to receivers and loudspeakers produces clear speech and beautiful music. Electric power in wires is changed to heat for ironing the frock, and heat per se can furnish a thermoelectric generator to reveal temperature. Electrons coursing through wires produce light. But again in converse fashion the light itself can serve as the releasing agent for electrons which "pop" out of the surface of metals. In photoelectric cells the radiant light provides the means whereby the metallic surface on which the light falls becomes a source of electrons. Such photoelectric cells make it possible, therefore, not to measure temperature, to produce physical motion, to obtain transfer of light to electrical power in large measure, but to measure intensity of light. Again there is no mechanical motion and the sheer power is small, but the phenomenon is used as a technique in measurement for various purposes. Of particular value these days, the photoelectric cell is the key translating device in sound motion pictures, in telephotography, and in television. Rapid light variations are deftly changed to electrical variations, which are enlarged by vacuum tube amplifiers.

Crystal, or Pressure, Electricity. In the establishment of an electrical potential, or voltage, by the method of electromagnetism first discovered by Faraday in 1831, it was pointed out that the power of mechanical motion is translated to electrical power. The motion involved is the relative motion of a wire and a magnetic field which are not in physical contact. The physical structure of the coil of wire and the magnet suffers practically no change. There may be a small

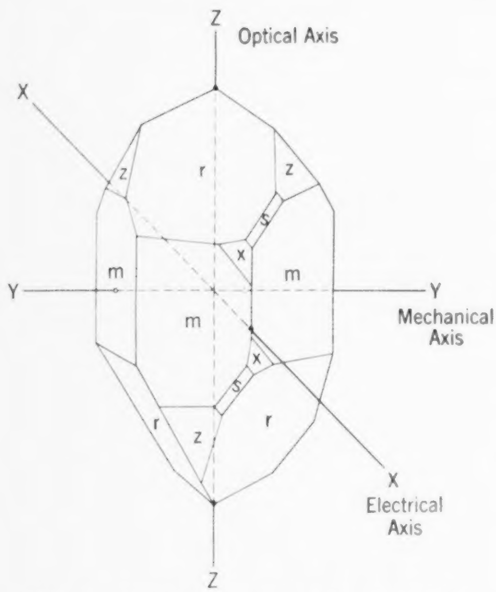


FIG. 2. IDEALIZED QUARTZ CRYSTAL

structural change, but that change plays no part in the mechanism of the energy translation. The mechanical power of motion has really played an indirect role. However, in certain forms of crystalline substances, mechanical power is directly changed to electric power. For example, if a crystal of quartz is mechanically twisted, compressed, or stretched, certain faces of the crystal acquire an electrical charge. This is indeed an entirely different kind of alliance between electrical power and other forms of power as presented in those alliances previously mentioned. It was pointed out that motions of the plates of a chemical battery do not enter into the matter at all; the wires of a thermocouple do not involve motion; the motion of the photosensitive surface of sodium, of potassium, of caesium, does not have a thing to do with the problem. In electromagnetic induction, distortion of the coils and magnets per se makes no contribution to the end result. However, in this last scheme of electric charge production, called "piezoelectric" or "pressure-electric," motion within the electrified object itself is a basically essential aspect of the phenomenon.

PIEZOELECTRICITY

Pyroelectric Crystals. Even though the quartz crystal is oftentimes regarded as a rather recent ally of electricity, it has been known for centuries to have electrical properties. Many years ago when the Dutch settled in Ceylon, they observed the natives playing with crystal tourmaline that had been thrown into a fire. Ashes clung to the heated crystal, and the name given to the crystal meant "ash attractor" in the Ceylonese language.

Magnetic attraction was a common phenomenon, and it is likely that the tourmaline was thought to acquire attractive properties in the fire. It is now believed that the phenomenon was pyroelectric. The first scientific paper regarding this subject was read before The French Academy. An English translation, 1742, was entitled "Of a Magnetical Stone Brought from the Island of Ceylon." In 1756, a German, writing under the Latinized name of Aepinus, presented the first rather comprehensive treatment of the subject and identified the phenomenon as specifically electrical.

Surprising as it may seem, a "History of Electricity" was written in 1767 by Joseph Priestley, discoverer of oxygen. In that history, the "ash attractor" phenomenon is listed as "electricity of the tourmaline."

Further investigation in this field was reported in a paper by A. C. Becquerel in 1828. He described experiments in which mechanical stress was applied to quartz and other crystals to produce a charge. Since it is now definitely known that some of those crystals are not piezoelectric, it is likely that the charges produced were not the result of mechanical strain but of the sheer contact incident to friction.

Pierre and Jacques Curie. Before Pierre Curie was stirred in 1896 by a later Becquerel (Henri) to study radioactivity, he and his brother, Jacques, knowing of the work of A. C. Becquerel, carried on researches on crystal electricity and published their results in 1880. It was they who first discovered the real pressure-electric effect and thereby introduced an entirely new concept of the interrelations of mechanical energy and electrical energy. In nature's treasure chest another jewel had been found. Truth is like a precious gem—it has many

facets. The Curies not only discovered the qualitative nature of piezoelectricity but also studied the phenomenon quantitatively. They made measurements of the voltages produced by unit pressures parallel to the principal axes of the crystals. One year later Lippman suggested that the crystal would be mechanically deformed if subjected to an electrical field, that is, connected to a source of voltage such as a chemical battery. The Curies promptly verified this prediction, and so the piezoelectric effect became recognized not only as an electromechanical but also a mechanicoelectrical phenomenon.

The piezoelectric effect, an intrinsically different alliance among the many entangling alliances in which electricity enters, took its place as a new actor playing an absolutely different role in the many relationships and interchanges of energy. It is not an uncommon phenomenon. Many crystals can be given an electric charge on their faces by applying to them a direct mechanical twist or squeeze or tension. Particularly significant is the reciprocal aspect of electrical charge production by distortion of the crystal itself. If an electric charge from a voltaic battery or other source is applied to the faces of the crystal, a mechanical contraction or expansion or twist of the crystal results. Since crystals are usually definitely elastic, they may be set in mechanical vibration along some dimension by the application of an electrical charge. In this direct association of electrical charge and mechanical motion, there comes into the realm of electrical science an entirely different philosophy and possibility of application than those that apply to other fundamentally basic electrical phenomena.

Modus Operandi of Piezoelectricity. As has been stated, electrons and protons are the building stones of the atoms of all substances. In many, perhaps in most substances, and particularly in the noncrystalline form, the atoms are in great confusion; they are in great disarrangement and move about in chaotic, random, and restless fashion.

However, the outward appearance of crystals (Fig. 2), irregular in shape to be sure but very symmetrical and systematic in that irregularity, presents evidence of great regularity of atomic and molecular arrangement. Many crystals assume very precise and beautifully regular angles, shapes, and facets. Furthermore, the inner architecture of the atoms and molecules is the result of definite and orderly patterns of grouping and alignment. By X-ray studies of crystals the orderly groupings of their atoms are recognized and the distances between the atoms of many molecules in crystals are quite well established in their precise alignments. Furthermore, the electrons within the atoms

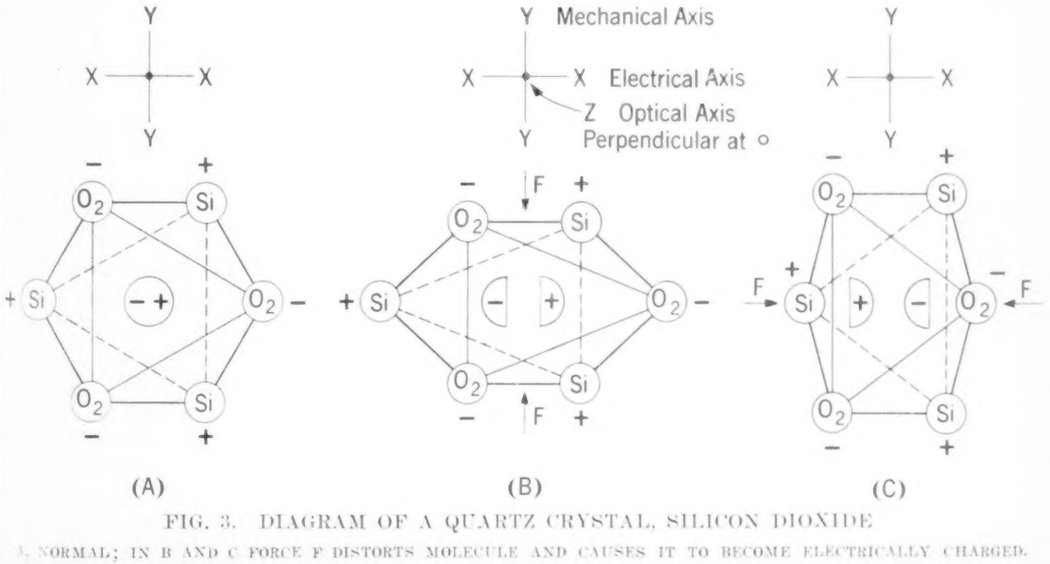


FIG. 3. DIAGRAM OF A QUARTZ CRYSTAL, SILICON DIOXIDE

A, NORMAL; IN B AND C FORCE F DISTORTS MOLECULE AND CAUSES IT TO BECOME ELECTRICALLY CHARGED.

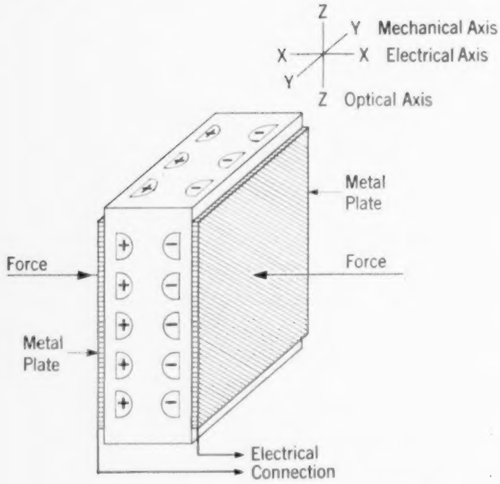


FIG. 4. TRANSFORMING ENERGY
MECHANICAL ENERGY BECOMES ELECTRICAL ENERGY AS FORCE IS APPLIED TO PLATES HOLDING CRYSTAL.

and molecules of crystals are arranged in regular fashion, which presents the possibility that a change in shape of the crystal would produce such a rearrangement of electrons that one portion of the crystal would have a seeming excess of electrons and another portion a scarcity of electrons. Thus would be brought into being an electrically charged crystal, as this excess and dearth would happen simultaneously to millions and millions of molecules.

In Figure 3A is depicted the approximate arrangements of positive and negative charges in a molecule of quartz. Looking down along the optical axis of a quartz crystal, one would see an equally angled hexagon. Quartz is an oxide of silicon, SiO_2. The silicon atoms have positive charges and the O_2 have negative charges. The combined effect of the three positive charges is the same as though all three were at the center of the equilateral triangle of which they form the corners. The same is true of the three negative charges. At the center of the hexagon the two opposite charge effects are equal, and the crystal is neutral electrically. Mechanical energy is necessary to disarrange the electrical neutrality and separate the positive and negative charges at the center. When the crystal is squeezed from top and bottom, the center of "positiveness" is no longer at the original central point but has moved to the right (Fig. 3B). Likewise, the center of negativeness has moved to the left. It took work to bring about this separation, and there is electrical evidence of that work because the right portion of the molecule is positively charged and the left portion is negatively charged.

When the squeeze is applied horizontally rather than vertically (Fig. 3C), the left-hand portion of the crystal molecule gets a positive charge and the right-hand portion a negative charge.

The arrangement of atoms and their accompanying charges in quartz happens to be such that mechanical force and motion change the positions of the centers of "positiveness" and "negativeness," and the crystal acquires an electrified condition, evidence that energy has been transformed. In other words, the crystal is pressure-electric, piezoelectric. This phenomenon does not occur in all crystals. Based on the symmetrical arrangements of their molecules, crystals may be grouped under thirty-two classifications of which twenty are piezoelectric and twelve are not.

The piezoelectric effect, like so many basic phenomena, has a long and laboriously earned heritage. As has been said, the brothers Curie first quantitatively studied a quartz crystal by putting a weight on the surface and measuring the charge, the magnitude of which was proportional to the applied weight. In Rochelle salt crystals the electrical voltages arising are greater under the same distortion than for quartz. With a sharp, heavy blow as much as 2,000 volts can be produced on the faces of a Rochelle salt crystal. A small neon lamp may be made to flash by the direct transformation of mechanical power to electrical power and finally to light. When such a crystal is connected to amplifier and loud-speaker, very slight taps on the crystal become loud crashes of sound. The tiny jarrings of the balance wheel of a watch placed on the crystal produce enough distortion of the crystal and consequent voltage to make the ticking of the watch blast out of a loud-speaker.

A narrow and thin plate of Rochelle salt crystal about the size of an army lieutenant's bar serves very well as a microphone. The Lilliputian impact of the sound waves of speech and music of the order of one micro-

pound distorts the crystal sufficiently to give rise to electrical charges which can be amplified. The variable resistance microphone, such as the carbon transmitter, and the electrodynamic and condenser microphones are now joined by the crystal microphone to translate the mechanical variations of sound waves to electrical variations.

In Figure 4 the central block is a piezoelectric crystal. Metal electrodes are attached to the side faces of the crystal. If forces are applied as indicated by the arrows to squeeze the crystal horizontally, the right surface of the crystal will acquire a negative charge and the left surface a positive charge. If the faces of the crystal were pulled, they would be charged oppositely. The actual "thinning" of the crystal by the squeezing forces would be very small, particularly in the case of quartz, since it is a hard substance. If a negative electric charge were applied to the right face and a positive charge to the left face, then the crystal slab would be squeezed. If two slabs of Rochelle salt 10 millimeters thick and 4 inches long are held together and poled in opposite directions so that one slab expands when voltage is applied and the other contracts, the direct change of electrical energy to mechanical energy is nicely visible. The arrangement above-described reminds one of a bimetallic thermostat. With only 90 volts applied, a direct motion of a quarter of an inch of the end of the dual crystal is produced.

Applications

Piezoelectricity Grows Up. In general the piezoelectric effect remained a scientific curiosity until the war of 1914–1918. During its youth, it had been the subject of considerable scientific investigation. Lord Kelvin, the eminent and famous electrical engineer and physicist, proposed in 1893 a mechanical model to explain the cause of piezoelectricity and was able to calculate the numerical relations involved. In 1910 in the *Lehrbuch der Kristall Physik* Voigt gave the mathematical expressions relating stresses, strains, fields, and polarizations of crystals.

During World War I Professor Langevin in Paris devised a quartz plate receiving device for the purpose of detecting the underwater sound waves of submarines. Conversely, if electrical charges were applied to the quartz plate of his device, the crystal would expand and contract and send out a sound wave. As he did not perfect his detector till after that war, it was not used at that time actually to detect submarines. His apparatus was, and is, extensively used to determine rapidly the depth of the ocean by timing the sound echo from the bottom.

During the years in which Langevin was working in the field of piezoelectricity, A. M. Nicolson of the Western Electric Company was experimenting in the same field. Using Rochelle salt crystals, which give much larger piezoelectric charges and displacements than quartz, he constructed and demonstrated microphones, loudspeakers, and electric phonograph "pickups." However, these uses of the crystal had no particular advantages over other previously well-known techniques. The direct alliance between motion and charge was still in the category of a curiosity and was not yet a particularly and especially talented phenomenon to achieve a practical purpose not otherwise possible.

Crystal Vibrations. Crystals are elastic and therefore, like a coiled spring, vibrate within themselves. A plucked string and a rigid rod vibrate visibly. A solid block of material like quartz can vibrate in various fashions. A cube of jelly will shiver and swing and sway and totter forward and back. This "tottering" of an elastic mass is called a shearing vibration. If a slab of quartz is squeezed, it will start to vibrate along its length when the force is suddenly released.

A crystal plate is an extremely complex vibratory system with a large number of degrees of freedom, that is, possibilities of motion. These various possibilities are, for the most part, combinations of certain fundamental types of vibration. The general relation between stress and strain, which in an ordinary isotropic medium involves only two constants, requires six constants in crystal quartz. The choice of a particular constant, or constants, that enters into a given mode of vibration depends upon the orientation of the plate with respect to origi-

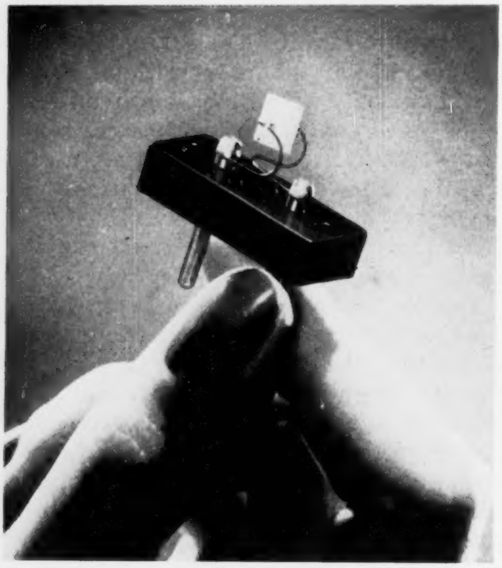


FIG. 5. FREQUENCY CONTROL CRYSTAL
EACH FREQUENCY MODULATION (FM) SET REQUIRES 10 CRYSTALS LIKE THE ABOVE. EACH TANK RADIO SET USES 70 AND ARTILLERY SETS CONTAIN 110.

nal crystal axes and the particular type of vibration; whether longitudinal, transverse, shear, etc.

A crystal or any elastic object has a number of frequencies at which its vibration may be maintained with small impulses from the outside. These are its natural frequencies. It can be forced to vibrate at any frequency by the application of sufficiently great outside forces, but at certain particular frequencies its vibration will continue for a considerable time when once started and this vibration can be maintained with very little energy if the force is applied in step, in tune or in synchronism. The block of crystal acts like a pendulum. The frequency of a mechanical pendulum depends on its length. The frequency of a particular quartz plate depends on its dimensions and its elastic constants. The elastic constants of quartz are high, as evidenced by the fact that sound, which is a mechanical vibration, travels along a particular path through quartz at the rate of about 14,000 feet per second; a velocity comparable to that in steel and nickel. Since quartz plates can be made small and thin and since quartz is highly elastic, very high frequency of vibration can be achieved by this technique. Thousands of vibrations per second and even millions of cycles per second enter the picture. The significantly important idea about a quartz "pendulum" is that its mechanical vibration is directly linked to electrical changes or vibrations. Since a particular quartz plate has a particular natural frequency mechanically, it will be directly allied with that same frequency of electrical vibration. In all sorts of vacuum tube oscillators and generators which provide alternating electric currents of high frequency and in all sorts of communication circuits, it has always been significant that there were no moving mechanical parts. The electric currents were oscillating, and the electrons were scampering, but the coils, condensers, wire, and vacuum tube parts did not mechanically move, and mechanical vibrations had nothing to do with the matter. But the mechanical vibrations and the natural frequencies of quartz plates have now entered the realm of, and play a part in, electrical vibratory systems. The mechanical vibrations per se are the crux of the matter, and it is striking to realize that mechanical vibrations are present and directly play a role in electrical systems. Nicholson used a Rochelle salt crystal with its association of mechanical vibrations and electrical vibrations to serve as a generator of electrical vibrations. The vibration was started when the circuit was closed. With a vacuum tube amplifier in the system, it fed back a bit of electric power to keep the crystal mechanically vibrating by the converse piezoelectric effect. The device thus served as a primary source, a crystal oscillating source of alternating current. This was indeed a new concept, a new technique.

Professor G. W. Pierce of Harvard University made important contributions to this new technique. Professor W. G. Cady of Wesleyan University first showed that quartz could be used not only to produce but also to control nicely and precisely the generating of electric currents by vacuum tube oscillators of the previously known type. These crystal-controlled oscillators were later applied to govern the frequency of broadcasting stations and mobile radio transmitters and receivers in war equipment (Figs. 5 and 6). The crystal plate is a sort of electrical vibration "governor."

FIG. 6. SET OF CRYSTAL PLATES IN A TANK FOR ITS RADIO TRANSMITTER

THE OPERATOR PLUGS IN THE PROPER PLATES FOR THE DESIRED FREQUENCIES TO BE USED ON A PARTICULAR MISSION. THE PUSH-BUTTON CONTROL ON THE EXTREME RIGHT PERMITS QUICK CHANGES OF OUTGOING WAVE.

Measurement of Seconds and Minutes. The swinging of the chandelier in the cathedral at Pisa suggested to Galileo that it might be used to measure time. Checking the time of the back and forth motions with his heart beat, he can be said to have invented the pendulum clock. Before and since Galileo's observation, the measurement of time has ever intrigued man's imagination and engaged his ingenious talents. The hour glass, the balance wheel of the watch, and many other schemes have been used as well as the ticktock of the stately clock. W. A. Marrison of the Bell Laboratories used the highly accurate alternating electric impulses of quartz crystals to measure time. This was a new and unique technique applied to a very old profession. The piezoelectric crystal did not have a pendulum but it did have a mechanical vibration due to its elastic properties and therefore was a sort of clock, a real electric clock of usually fine precision.

Of particular interest and significance is a recent announcement from Greenwich, England. For decades the word Greenwich has been synonymous with time, accurate time, world time, latitude and longitude. Purely mechanical devices—extra special chronometers and clocks, checked by the stars in the sky—have been used to measure time and tell time with great accuracy to just folks and to engineers and scientists wherever they may be on land or sea. Now it has been disclosed that the piezoelectric quartz crystal oscillator, a real electric clock, is to be put in service at Greenwich. For astronomical use, crystal clocks not only have great stability but also are completely free from the effect of the earth's force of gravity. At the earth's poles pendulum clocks swing faster

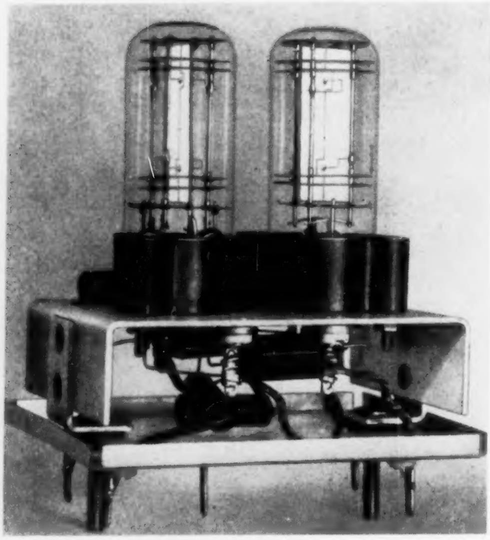


FIG. 7. CRYSTAL WAVE FILTER
THE QUARTZ PLATE IS PLACED IN A VACUUM BULB.

than at the equator, but crystal oscillators retain their precision of vibration wherever they may be taken on the earth's surface, deep in the ocean, or high up in the sky. Early in the development of crystal clocks, an accuracy of one part in a million was achieved. Now crystal clocks are available with a daily deviation of well under one part in a hundred million. To put it another way, these newest quartz crystal chronometers beautifully measure time to an accuracy of one one-thousandth of a second per day. The old faithful mechanical clocks at Greenwich which have served so well for many years are due for quite a shock, an electric shock, when they are put on the shelf by a shivering wafer of rock.

Electric Current Filters. A crystal plate has a particular and a sharply defined mechanical frequency of vibration. At this frequency it will keep vibrating with very little applied power. If it is placed in an electric circuit along which many alternating currents are traveling, the crystal acts as a "door" or "gate" to that electrical frequency which corresponds very precisely to its own electromechanical frequency. It tends to stifle the other frequencies but gives the "green light" to its own. Hence a quartz crystal plate would be a fine electric filter of electrical currents. It would provide a sharply resonant circuit. Professor Cady was the first to make this application of the electromechanical vibrating crystal. W. A. Marrison of the Bell Telephone Laboratories made further developments along this line and designed a filter for a narrow group or band of frequencies.

To the rapid developments in electrical vibrations with a direct mechanical accompaniment, L. Espenschied of the Bell Telephone Laboratories made a further significant contribution. Taking advantage of the knowledge of the so-called "equivalent electrical circuit" concept applied to a crystal, given by K. S. Van Dyke of Wesleyan University, Espenschied showed how to combine electromechanically vibrating crystals with other electrical elements in ladder type electrical networks to provide wider pass-bands than are available with crystals only. For such filters the detrimental effects of electrical resistance in the coils and condensers contribute to rounding off the attentuation-frequency relations and prevent the obtaining of as sharp a cutoff as can be obtained by crystals alone. The final step in utilizing crystals in wide-band crystal filters was made by W. P. Mason when he devised the "resistance compensated" lattice type of crystal electric wave filter. With this type of filter the electrical resistance in the concomitant coils and condensers produces only an additive loss independent of frequency and results in a filter with as sharp a cutoff as can be realized with crystals alone. This type of filter is used in the high-frequency carrier current telephone systems and in the coaxial system which simultaneously transmits 480 messages over one pair of wires. Following this development have come the significant and important researches of R. A. Heising, W. P. Mason and their associates—Lack, Bond, Willard, Sykes, McSkimin, Greenidge, D'heedene, Thurston, and Fair—of the Bell Telephone Laboratories. Now crystals with their electromechanical vibrations play an accompanying role with electrical vibrations per se to auxiliary coils and condensers in electrical arrays or networks of a wide variety and of wide capabilities and talents. These networks or filters have been directly responsible for the progress achieved in the wide

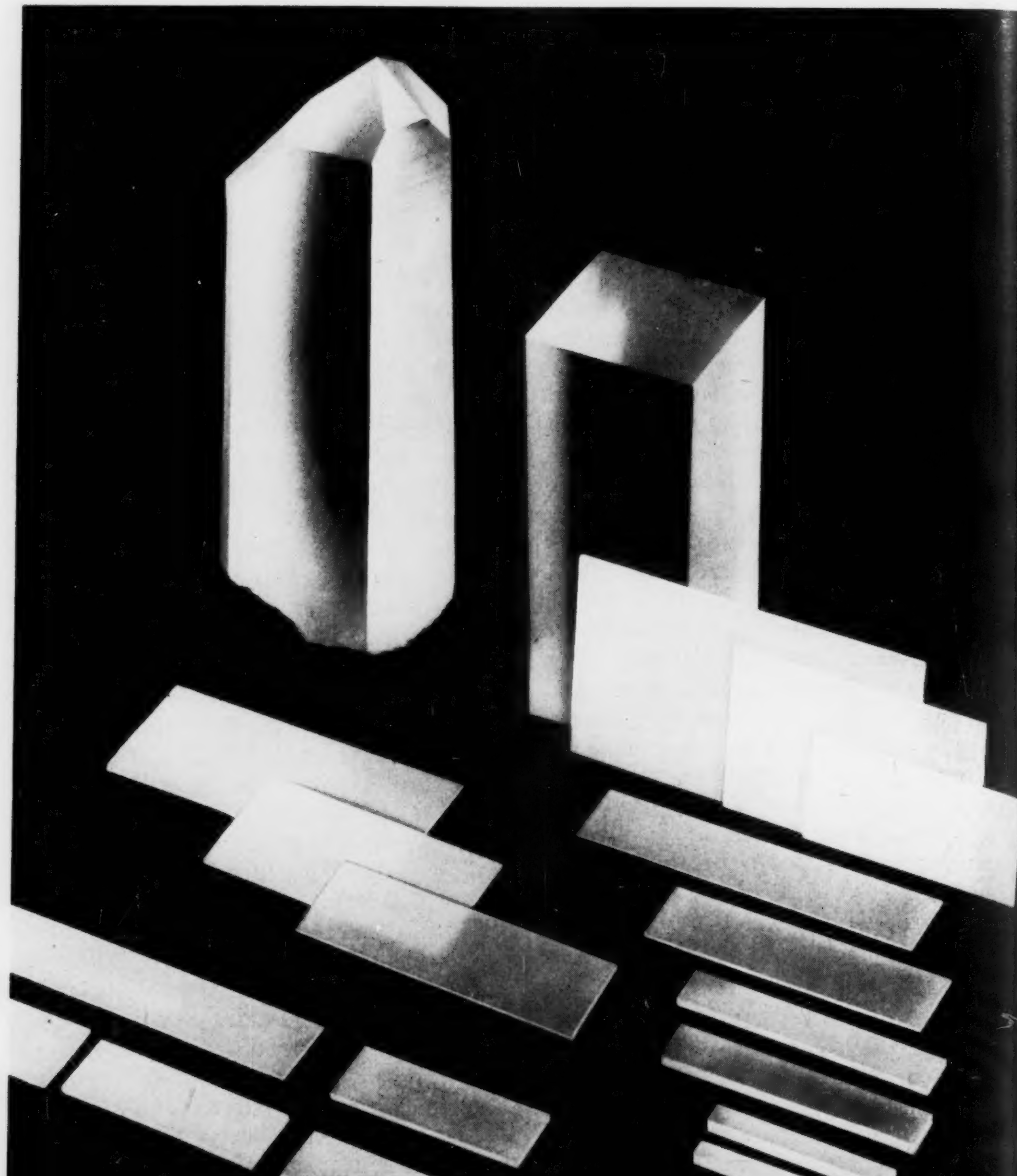
wave-band characteristics necessary when a number of telephone messages are sent simultaneously over the same pair of wires. Such electric wave filters (Fig. 7) provide very selective and sharply defined devices which with great nicety separate the array of currents carrying different telephone conversations over the same wires. The characteristic of the mechanical quartz plate with a particular natural frequency of vibration corresponding to that frequency of electric currents specifically aids in sharpening the edges of the electrical "door." An electric wave filter is a kind of electrical "door" which passes electric waves of wide array in frequency. But the "door" may have "rubber" edges like subway doors which provide a little leeway to passengers squeezing in. Good electrical filters or "doors" ought not to have "rubber" edges. Electrical vibrations either too few or too many in a particular case must not be allowed to "squeeze" through. Quartz crystals help make the wave limits of filters sharply defined and sharply different from other wave filters. Thus it is possible to bring wave channels closer together than by previous techniques. Through the discriminating talent of the sharply edged crystal electric wave filter, frequencies from 60,000 cycles to 2,060,000 cycles are nicely divided in 480 separate bands of frequencies, each about 4,000 cycles wide.

Quartz Crystals

Crystal Cuts. In this essay the basic phenomenon of piezoelectricity and its unique contribution in electrical vibrating systems have been presented in a general way. The details of theory and practice and design, all so necessary for the accomplishment of a practical operating system, are the combined contributions of many men and would fill many volumes. Quartz crystals are contributing in large measure to the war effort. Thousands and thousands of items of communication equipment on the home front and on the war front rely on detailed piezoelectric crystal engineering for their outstandingly successful operation. In 1943 one manufacturer alone provided 8,000,000 quartz crystals for special war communication equipment. In 1939 about 20,000 were cut. The concluding part of this exposition will deal briefly and generally with some points about the various "cuts" of quartz plates (Fig. 8).

The native quartz crystal is really a thing of beauty. Its irregular regularity and multiple facets make an intriguing object. Many crystals are strikingly clear, and their surfaces are smooth as satin. Since the days of the Old Testament writers, quartz crystals have been a symbol of clarity and beauty. It is a common crystal and is found in many places throughout the world. Nature's laboratory with its gigantic test tubes seems to have done a particularly good job in Brazil. There in the river bottoms and in the rocky hills, quartz of high quality is found in great plentitude. Some crystals weigh ounces and fractions thereof; others weigh hundreds of pounds. One highly perfect individual crystal weighing about half a ton arrived in New York a year or so ago. Its 6 cubic feet of volume would make it the "Cullinan" of quartz crystals. All quartz is not of the same crystallographic shape. Figure 9 shows a particular side view of a particular crystal and the bird's-eye view of that crystal. About the only general statement that can be made about quartz crystals is that a bird's-eye view of all crystals always reveals an equal-angled hexagon and sometimes an equal-sided hexagon. A quartz crystal is a complicated structure. Its physical properties vary in different directions. Along different paths the coefficients of elasticity, the coefficients of thermal conduction, the coefficients of thermal expansion, the velocities of sound, the velocities of light, and the piezoelectric relations are different.

The natural frequencies of a particular plate wafer, block, or ring of quartz depend largely on its dimensions and how that plate is cut with respect to the different faces and axes of the original crystal. A particular plate may vibrate in various ways. It may simply expand and contract along one or more axes or may undergo a complicated motion of bending and shear. One is reminded of the motion of the accordion with its combination of squeeze, twist, and bending. Obviously if the temperature changes, the density changes, the coefficient of elasticity changes, the velocity of mechanical motion (sound) through it changes, and



About seven-eighths actual size

FIG. 8. BLOCK AND PLATES ARE SAWED OUT OF NATURAL CRYSTAL

finally, as the end result, the natural frequency of a particular "cut" changes.

In developing crystals for oscillators and communication circuits, extensive studies were undertaken in the Bell Telephone Laboratories to determine how "cuts" of different sorts were affected by the variable physical factors of quartz. Perhaps the particular physical property of a certain magnitude along one axis could be neutralized by slanting the cut to that axis so that the different magnitudes of that property would produce a null result. In other words, an attempt was made to find the "cut" best suited to a particular purpose.

X, Y, Z Axes. The vertical line perpendicular to the hexagonal cross section and passing through the center thereof is given the designation "Z-axis." It is also called the "optical axis." Light passing along that axis travels with uniform velocity. Light passing at some angle to the optical axis is doubly refracted, resulting in two different velocities.

The Y, or mechanical, axis is taken perpendicular to any pair of the three opposite faces. This axis is of course horizontal, assuming the Z-axis as the vertical axis, and intersects the Z-axis. The X, or electrical, axis also is horizontal and passes parallel to two opposite faces of the crystal. The X and Y axes are in the equatorial plane. The three axes are mutually perpendicular and intersect at the center of the hexagonal cross section (Fig. 9). One is reminded of the three co-ordinate axes of solid analytical geometry.

The first "cuts" used were X-cut and Y-cut. Both of these cuts have their width parallel to the Z-axis. The X-cut has its face perpendicular to the X-axis and its length parallel to the Y-axis. The Y-cut has its face perpendicular to the Y-axis and its length parallel to the X-axis. These three cuts and their orientation are shown in perspective in Figure 10.

If an alternating voltage, i.e., an alternating electrical charge, is applied to an X-cut plate along the electrical axis, X, the plate expands and contracts lengthwise along the mechanical axis, Y; namely, at right angles to the charge displacement. The frequency

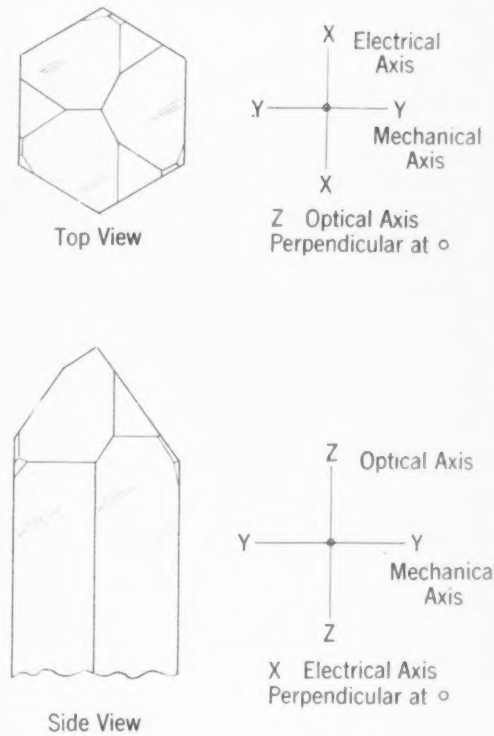


FIG. 9. QUARTZ CRYSTAL

in this case depends largely on the length of the crystal, that is, its length along the Y-axis.

If an alternating voltage is applied to a Y-cut plate along the mechanical axis, Y, then the resultant motion is a shear. The two faces of the Y-cut crystal move back and forth along the X-axis in their own plane. Again one is reminded of a cube of jelly which totters. The top horizontal plane of the jelly cube moves back and forth in its own horizontal plane parallel to the fixed lower plane resting on the dinner plate.

As indicated in Figure 3, a motion along the electrical axis, X, will give rise to charges displaced along this same axis. Conversely, if an electric charge is applied along the X-axis, one gets a mechanical displacement along that X-axis. In other words, the mechanical and electrical displacements are not at right angles but in the same direction. Vibrations may be longitudinal or transverse with respect to the electric field. Thus the X-cut crystal can be made to vibrate along its length parallel to the mechanical axis Y, or it can be made to vibrate along its thick-

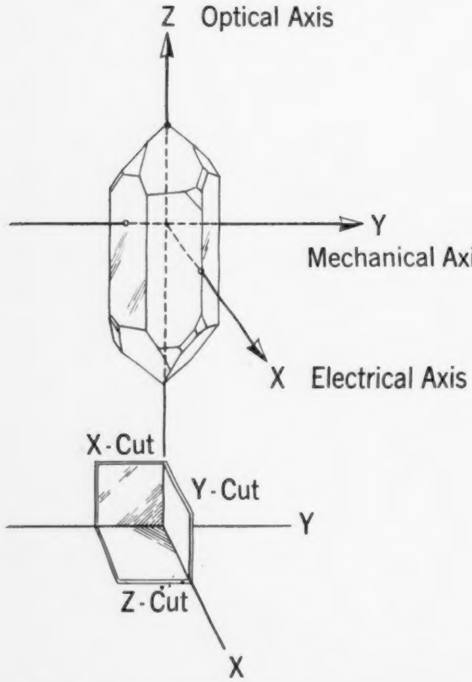


FIG. 10. ORIENTED QUARTZ CRYSTAL
SHOWING CUTS IN RELATION TO NATURAL CRYSTAL.

ness parallel to the electrical axis, X. The two surfaces would move at right angles to their own planes, and the plate would alternately get thinner and thicker. One is again reminded of the motion of the accordion. Obviously the frequency involved when the plate is caused to vibrate lengthwise along the Y-axis would be slower than when it vibrated along its thickness, or perhaps one ought to say its thinness.

If an effort were made to get a high frequency by utilizing the vibrations along its thinness, slight changes in various conditions might cause the controlling vibrations to shift from its frequency to an upper harmonic of its Y-frequency. The most common cause for this undesirable condition would be a temperature change. In other words, X-cuts and Y-cuts are very vulnerable to temperature changes.

Crystal Frequency. When an X-cut crystal is executing X-axis vibrations, its thinness largely determines the frequency of its natural mechanical vibration and of course its accompanying alternations of electric current. As in all vibrating systems, frequency and wave-length are related by the simple equation:

Frequency × Wave-length = Velocity

In this case, the "thinness" of the X-cut plate is one-half of a wave-length for the mechanical vibration in the quartz. The two surfaces of the plate are loops or antinodes of motion in the longitudinal vibration. If the plate is vibrating in its fundamental, then its thickness is the distance between two adjacent loops of motion and is a half wave-length. However, the actual situation is not as simple as above suggested. The vibration is not strictly longitudinal but has a shear component.

However, if one knows the velocity of mechanical waves, that is, of sound, in quartz along the particular path concerned, then a good idea of the numerical value of the mechanical frequency and electrical frequency of a particular plate of X-cut crystal for X vibrations can be found by doubling the thickness of the plate and dividing the 2t into the velocity.

For example, a .1 inch plate gives a wave-length of .2 inch. Since $F = V \div L$, the resulting frequency is 843,400 cycles or 843.4 kilocycles per second. This calculation gives a fair approximation as to the order of magnitude of F, since V is not accurately known. It does give a good notion of the fundamental mechanical wave phenomenon involved.

Velocity of waves in an elastic medium is a function of the square root of the coefficient of elasticity and the square root of the density.

$$V = \sqrt{\frac{E}{D}}$$

The equation for vibration of quartz crystal plates in such cases as above can be written

$$F = \frac{1}{2t} \sqrt{\frac{E}{D}}$$

with proper attention to units.

These equations are difficult to use exactly as such since the value of E which controls the velocity along the different axes varies with the cut of the crystal. Furthermore, on account of the shear motions, the length and breadth dimensions also play a part in the frequency of the mechanical vibrations.

From the equation F = Velocity ÷ 2t, giving the mechanical frequency at which a crystal plate vibrates, it is readily seen that since the numerator is large, 14,000 feet per second, a small change in thickness of a thin plate produces a considerable change in that frequency. Since the electrical frequency accompanying the mechanical frequency must be highly accurate in communication equipment, the precision with which crystal plates are ground elicits great admiration of the skill of the artificer. Thousandths, ten-thousandths, and millionths of an inch are the terms necessary to describe the dimensions to which crystals are ground and polished.

Assume, as before, a crystal is .100000 inch thick, thereby supplying a frequency of about 843,400 cycles per second. A change in thickness of a thousandth of an inch to .101000 inch produces a reduction of 8,350 cycles. This change is a bit less than one per cent. An increase of a ten-thousandth and a hundred-thousandth to .100100 and .100010 reduces the frequency by 880 and 84 cycles respectively, a change of about .1 and .01 per cent. Finally, if the thickness of this assumed plate were increased by a millionth of an inch to .100001 inch, a change of 10 cycles would result. This is a change of about .001 per cent. The latter values of .01 and .001 per cent are very small and, as pointed out in the succeeding paragraph, frequencies can be achieved which vary by about .002 per cent. Hence it is seen that the thickness must be prescribed within very tiny tolerances. Likewise, the length and breadth must be controlled with extreme care.

The fine techniques and niceties of the jewel maker and the lapidarist are surpassed in this new task of cutting and grinding crystals for the manufacture of electrical communication apparatus.

Temperature Affects Frequency. To get quartz crystal electromechanical vibrators of more stable and reliable character independent of temperature changes, a very thorough and extensive investigation was embarked upon in the Bell Telephone Laboratories. The accompanying photograph (Fig. 11) shows an enlarged model of a quartz crystal and plates cut at various angles and

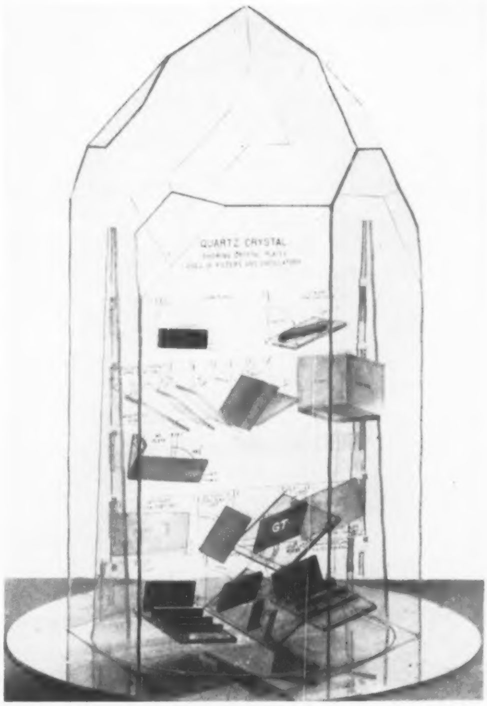


FIG. 11. MODEL OF QUARTZ CRYSTAL
SHOWS ORIENTATION OF VARIOUS CUTS IN CRYSTAL.

rotations with respect to the X, Y, and Z axes. One cut tried early by W. A. Marrison was a doughnut-shaped piece of quartz. From Figure 12 it will be observed that the Y-axis runs through the center of the hole. By properly proportioning the dimensions, the change in frequency with temperature can be made essentially zero. Crystals of this type were used in early forms of crystal clocks for keeping time very accurately and for frequency standards in various fields of endeavor. They have now been replaced by GT-type crystals described below. The 60-cycle frequency of great power generators is controlled by some such crystal structure so that the electric motor clocks in the home and in the office may be nicely correct.

A piece of rock weighing about an ounce acts as a governor to control the speed of rotation of a giant structure weighing tons and converting thousands of mechanical horsepower to electrical power. One is reminded of David and Goliath.

The doughnut-shaped crystals did not lend themselves very well to electric wave filters in carrier telephone systems as typified by

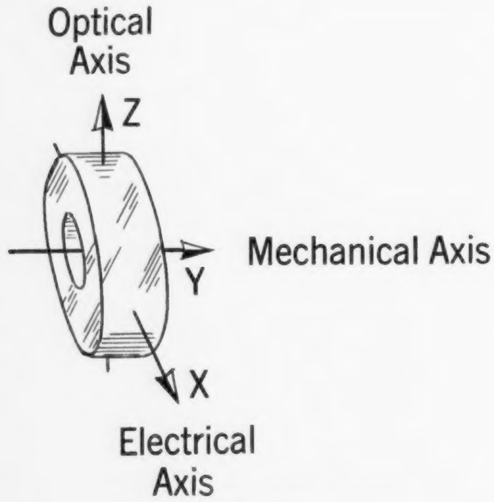


FIG. 12. DOUGHNUT CUT
THIS CUT HAS A ZERO TEMPERATURE COEFFICIENT.

the 480-channel coaxial cable system, in radio broadcasting transmitters, in radio transmitters and receivers for airplanes and tanks, and in various war devices. Therefore, crystal plates, or wafers, are used. These plates were formerly mounted in aluminum cans. Exactly cut and ground to the desired size and coated with very thin metallic electrodes, a recently developed technique puts the plates inside a vacuum bulb as shown in Figure 7. The absence of air around the plates increases the delicacy and sensitivity of operation.

One of the cuts worthy of particular mention is the so-called GT-cut devised by W. P. Mason. This cut resulted in especially fine and practical crystal plates which are practically insensitive to temperature changes. The manner of the GT-cut can be generally observed in Figure 11. Over a range of 100 degrees centigrade, i.e., from the freezing to the boiling point of water (180 degrees Fahrenheit), the GT-cut crystal is constant in frequency capability to about two parts per million of cycles per degree. Other well-known cuts are the AT, BT, and NT. The Radio Corporation of America developed an excellent cut, called the "V."

The fundamental studies of crystals and crystal cuts and crystal functioning in communication facilities have been accompanied by extensive research on methods of cutting and grinding quartz plates to the orientations and dimensions desired. The grinding tolerances are very small, and the success in producing high-precision crystals in large numbers for war purposes during the last few years has been possible primarily because of these studies.

Epilogue

The piezoelectric effect is a most fascinating phenomenon. Quartz crystals can be appropriately called the latest ally of electricity. This entire field of endeavor is unique in the saga of electrical engineering because in the application of quartz crystal plates to electrical communication a vibrating mechanical structure is an integral operating part of an electrical system. A mechanical device directly contributes electrically to the functioning of an electrical system.

The piezoelectric alliance is not a suitable or efficient method of translating mechanical power to electrical power. Like the thermoelectric and photoelectric alliances, its talent is not applicable where great amounts of power are needed for the world's tasks. To be sure, in piezoelectric generators for underwater signalling, sound waves embodying power in the order of a kilowatt are now used. The potent mechanical vibrations are imparted to the crystal by vacuum tube oscillators and amplifiers. However, one kilowatt is not gigantic so it may be correctly stated that the really big jobs are done through the chemical and electromagnetic alliances. However, in those branches of engineering where high-frequency vibrations and oscillations play a role, the direct electromechanical converse relations of the piezoelectric effect so nicely present in crystal quartz serve admirably.

As has been said very appropriately by W. P. Mason:

> The science of piezoelectricity was born about 64 years ago, lay dormant for about 40 years, but during the last 25 years has advanced at such a rate that it can be regarded as one of the foundation stones of the whole art and practice of electrical communication.

In Dr. Mason's significant statement, the word "stone" is for the first time used literally as well as figuratively in electrical engineering.

GOKKANOSHO: A REMOTE CORNER OF JAPAN

By JOHN F. EMBREE

EIGHT centuries ago Japan was torn with civil war, a war of two great clans, the Minamoto and the Taira. In 1185 there was a final disastrous sea battle between them at Shimonoseki during which a child emperor, held by the Taira, was drowned and the whole Taira clan wiped out. This, at any rate, is the orthodox historical account. Tradition, however, clings to the romantic belief that many of the defeated Taira warriors fled south into the wild mountain fastnesses of central Kyūshū, and the brothels of Shimonoseki were, for a brief spell, enriched with noble ladies. To this day, so it is said, descendants of the Taira are to be found in Gokkanosho (Fig. 1), a district far in the mountains of Kumamoto, approachable only by foot.

A more prosaic, if more scientific, interest centers on Gokkanosho as an example of Japanese mountaineer life. Gokkanosho means five settlements or families and originally consisted of five *mura*, or villages: Kureko, Momigi, Hagi, Nitao, and Shiibaru. For administrative purposes two other *mura* are now included (Kakisako and Kuriki), making a total of seven *mura* ranging in population from 150 to 2000 people, all governed by the same headman and council. The administrative office and headman are located in Kakisako, the largest one, but each *mura* has its own head, or *kuchō*, who takes care of local affairs.

In the summer of 1936, while making a field study of the social organization of Suye Mura, a Kumamoto rice farming village, I took a few days off for a pilgrimage to this interesting place which, while considered to be almost in another country by people of the village in which I was living, was actually less than twenty miles away.

To prepare for such an arduous journey by foot as that to the mountains of Gokkanosho, three things are regarded as essential by a Japanese: a small cotton towel, or *tenugui*, a hat, and tissue paper. The hat keeps off the sun and the rain, the *tenugui* serves to wipe the sweat from one's brow, and the tissue serves as handkerchief or toilet paper.

Three companions and myself were to leave the village at 6:30 in the morning, but, in good local style, we were not under way till after seven. Everyone wanted to know where we were off to at such an hour and all with knapsacks, and when they discovered that we were going to Gokkanosho they opened their eyes wide; no one in the village had ever been there. They wondered whether the people there were like other Japanese—since they did not eat rice they must be different from all right-thinking, rice-eating people!

From the neighboring village of Youra a bus took us well up into the mountains. In the valley where I had been living, the wide flood plain of the Kuma River is one vast irregular checkerboard of rice paddies. As one goes up toward the mountains, the rice fields gradually become scarcer and are replaced by forests, upland fields, and an occasional lumber mill.

After a couple of hours' ride, we came to Miyazono, a settlement of one house, located by a mountain stream. This house functioned as shop, hotel, and dwelling. The storekeeper informed us that the chief products of this region are charcoal and lumber and that the inhabitants eat wheat and millet. As rice is scarce, it is purchased only for special occasions.

Beyond Miyazono houses occur only at widely separated intervals and are bark or tin-roofed one-room shacks instead of the richly thatched cottages of the plains. Many people of the region make a living by carrying charcoal. We met three women carriers who said they make two trips of 20 *cho* ($1\frac{1}{2}$ miles) a day at 12 *sen* (4 cents) per sack, earning a total of 48 *sen* (16 cents). Stronger people, they said, can make three trips. Because their loads weigh up to 100 pounds (12 *kwan*), they must rest frequently, but they do not lack for beautiful scenery, nor do they

make machines of themselves. Frequent stops are made by some little stream to rest, chat, and munch a cucumber (Fig. 2).

We went along a narrow mountain trail where the mountains rose high all around leaving but little sky visible. The forests vibrated with the song of myriad insects. As we walked, the noise of a rushing mountain torrent sang constantly in our ears, and every now and then we caught a glimpse of the water tumbling from a rock and foaming into a bright green pool.

Some of this plentiful water power is harnessed for electricity, as evidenced by an imposing modern power house by the river. This plant supplies Kumamoto City with electric power, yet farm houses a few miles away are still using oil lamps (Fig. 3).

Finally, after several hours of tiring uphill walk, we reached the settlement of Kureko, one of the seven hamlets of Gokkanosho. The first regular farmhouse we came to was a tin-roofed hut near a bridge. Here some people directed us to the schoolhouse where we ex-

FIG. 1. JOURNEY THROUGH GOKKANOSHO

FIG. 2. CHARCOAL CARRIERS NEAR MIYAZONO

THESE WOMEN CARRY THEIR BURDENS ABOUT SIX MILES A DAY FOR THE EQUIVALENT OF SIXTEEN CENTS.

pected to spend the night. We walked on and up a steep path, feeling very tired, and finally came to a house. It was an old, dilapidated structure with a heavy thatched roof buried under a profusion of moss and bushy green plants—the kind of house a goblin might haunt, or a ghost of the Taira (Fig. 4).

A few steps farther on we came to the school, a small one-room wooden structure, but it was closed, the teacher being away on summer vacation. As we stood by the school gate wondering what to do for a night's lodging, a woman bent low under a load of faggots called a greeting to us. We told her our plight, and she invited us to follow her just as casually as if strangers were an everyday occurrence. So we walked along behind her by upland fields of maize and potatoes, millet and buckwheat. On the steep mountain sides across the valley we could see great squares of cleared land. These were the *koba*, or mountain fields, where *hie*, a poor sort of mountain grain, is grown. Every now and then we passed other dwellings, each more overgrown than the last, and finally came to the home of our guide, a house with a roof as fertile as any. One would never suspect it of being the local headman's house. But when we learned that one man has been headman for twenty years, we realized that time in Gokkonosho is not the same thing as time in Tokyo.

On arrival at the home of our volunteer hostess, we gave the headman's wife some of the rice which we had brought with us. She took it and left us. Shortly afterwards, having changed from working clothes to a full-length kimono and having combed her hair, she reappeared and served tea.

About dusk, after we had each had a bath in turn in a rude tub out in the back yard, the master of the house, his son, and the son's wife returned home from their day's work in the fields. After washing and changing, they came in and sat by the fire pit. Then supper was served to them—a potato broth helped out with pickles. We were served our rice in the guest room, but after finishing we joined the family around the fire pit, partly because the evening had become chilly, but more to become acquainted with our host, Mr. Kuramoto, and his family.

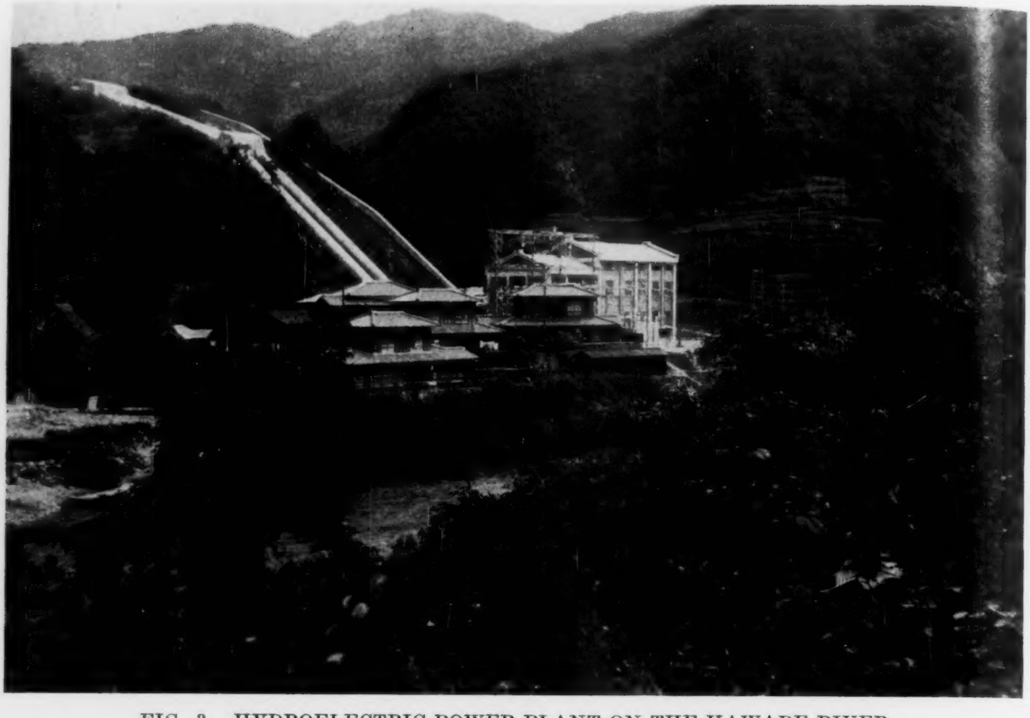


FIG. 3. HYDROELECTRIC POWER PLANT ON THE KAWABE RIVER
THE LOCAL FARMERS USE OIL LAMPS WHILE THEIR POWER PLANT ILLUMINATES A DISTANT CITY, KUMAMOTO.

As head of the hamlet of Kureko, Mr. Kuramoto says he receives 80 *sen* a year from each of about thirty families. Marriages and deaths may be recorded by him instead of at the central administrative office of Gokkanosho, which is many miles away by tortuous mountain trails.

After a little further conversation, I learned that the daughter-in-law was from the same community of Kureko. As women of other regions cannot do the hard work required of a Gokkanosho woman, the men marry women of the same region, often of the same settlement. As there are only thirty families in Kureko, everyone must be fairly closely related, though the inhabitants maintain the fiction that they do not marry relatives.

Seven people live in the Kuramoto house: Kuramoto and his wife, their first son and his wife, and three grandchildren. Three other grandchildren died young, the price of mountain life, where infants stand scarcely a fifty-fifty chance to live. A few years ago there was a midwife in Kureko, trained at Kumamoto City on the recommendation of the village headman, but she was not called in by very many mothers. A woman usually has her baby alone and washes it herself. Her mother or brother may give her a pail of water, but that is all. Mrs. Kuramoto remarked that if a woman cannot wash her own baby when it is born, she is a useless woman. A doctor is never called here unless a person is in a critical condition, and by the time the physician arrives from many miles away, the patient is usually dead.

There is a belief in other parts of Japan that several brothers and their families all live under one roof in Gokkanosho, but this is not true. In former times, however, they may have done so, Kuramoto conceded. Co-operation between households is characteristic of life in Kureko as in other parts of rural Japan. For instance, two or three households group together to clear one another's mountain fields (*koba*) or to collect firewood. If a new house is built, the whole hamlet assists in the work. By this co-operation the families get the work done more efficiently; the practice also makes for friendship among neighbors.

As in other parts of Japan, a go-between is used in marriage negotiations. This go-between is often the uncle or elder sister's husband. Unlike most places in Japan, there are no naming ceremony parties. At a funeral the entire hamlet helps, but, unlike other parts of Kumamoto, four young male relatives of the deceased, usually nephews, carry the coffin. Possibly because more relatives are on hand, functions which are relegated to nonrelatives in other places are performed by relatives in Gokkanosho.

As we talked of life in the mountains, the daughter-in-law made up our quilts for sleeping and washed the supper dishes. We soon retired, glad of the warmth of the thick quilts and of a good night's rest.

In the morning the family was up at five. After breakfast, the dishes were again washed—in cold water—the fingers making a characteristic rubbing sound against the glaze of the bowls. The daughter-in-law did all this, carrying the baby on her back as she worked.

A remarkable blessing of the region, which we discovered after spending the night, was a lack of mosquitoes. This is attributed to the cold. The cold is also given as a reason for not growing good rice, although the rough terrain is probably a more important one.

One does not punch a time clock in rural Japan, so after breakfast the men sat about a while for a smoke and chat, then the elder Kuramoto set off for the hillside five miles away, while his son sharpened a sickle on a grindstone (Figs. 5 and 6). This done, he too set off, and his wife followed soon after carrying a lunch box of wheat in a basketry bag on her back. Water is carried to work in bamboo containers. The small children all stayed home and spent the morning in play to the accompaniment of a pleasantly noisy mountain stream.

We spent the morning exploring the hamlet. From the children we learned about the local school. It has, they said, one teacher and forty-eight pupils; there is a six-year course; and also a "completing" course (Hoshugakkō) of one year, all taught by the one teacher. No children are sent away to

FIG. 4. A THATCHED ROOF, "BEARDED WITH MOSS AND IN GARMENTS GREEN"
IN THE FOREGROUND IS A VEGETABLE GARDEN OF CORN AND TARO. A MOUNTAINSIDE FORMS THE BACKGROUND.

FIG. 5. PREPARING FOR THE DAY'S WORK IN THE FIELDS
THE BOY SHARPENS A SICKLE WHILE HIS MOTHER "DOES THE DISHES." BEHIND HER IS THE "BATHROOM."

school for there is no money in Kureko for such luxuries. By way of extracurricular reading I noticed two books in our host's house, one on the growing of secondary crops in mountain villages and one entitled *How to Marry*.

As the *koba*, or mountain fields, are two or three miles off and difficult of access, people do not come home for lunch. It takes much time to care for *koba*, so the people do not have the leisure seasons of the rice plains people. Whenever Mrs. Kuramoto goes to Fukada to visit a relative there, she envies the people sitting around.

One *koba* is productive for about four years, though a good one might last a couple of years longer. When the soil is depleted a new one must be prepared in a different place. Bushes are burnt as fertilizer, no other fertilizer being used. A new field made one year has its growth cut and burnt and is then left to lie fallow till the following spring when it is planted. The series of crops is usually buckwheat the first year, millet (*hie*) the second, red (*azuki*) bean the third, and finally Italian millet (*awa*) in the fourth year. Fields where corn is planted are always those where buckwheat, *azuki*, and millet have once been planted. The few little rice fields in Kureko average 4 *se* (0.1 acre) and total only 1 *cho* and a *tan* (2.7 acres) in the hamlet (in other parts of Kumamoto each landowner might have 1 or 2 *cho* of rice land). The average *koba* land and upland field area is over 1 *cho* (individual *koba* are 1 to 2 *tan*). Human fertilizer is used in the rice fields, an indication of their special value.

The chief export products of Kureko are mushrooms, bamboo shoots, and tea, also some red beans and *konyaku* tuber. Supplies come from a branch of the Miyazono store; goods are paid for in cash or in red beans (in the rice regions of the plains small purchases are paid for in rice).

A sign of change in life here is the plan to inaugurate a farmers' association, similar to farmers' associations in the rice-growing regions, for the marketing of mushrooms.

Telegrams reach remote Kureko by foot from Haramachi, another hamlet of Gokkanosho, and a postman comes from Kobaru.

Of over thirty families, three take a newspaper: the hamlet head, the schoolteacher, and the forestry office. Electricity is not available here; only oil lamps and the old-fashioned square lanterns called *andon* are used. Wood, not charcoal, is used in the fire pit. There are three phonographs but no radio. A teacher tried a radio once, but found it difficult to run, since he depended on batteries. Other contact with the outside world comes through occasional trips to Fukada or other villages of the plains and through itinerant peddlers or merchants who come occasionally to sell something or to buy mushrooms. Most of Japan is overrun with bicycles, but there is not a single one in Kureko. The only practical way to travel the steep and narrow mountain paths is on two legs.

Work varies with the season. In winter, when the fields are covered with snow, people must sit at home. In summer, however, everyone rises at five, works till noon and, after a lunch in the fields, resumes work till five or six and retires at ten. Wheat or millet must be boiled for the next day's lunch box the night before.

There are plenty of vitamins in the food of these mountaineers. White potatoes and pickled radish and greens form the staples of diet. Rice is served only on special occasions. But there is a long list of other vegetable foods including various herbs and greens, sweet potato, cucumber, pumpkin, maize, millet (both *hie* and *awa*), wheat, buckwheat, and various beans. Eggs occasionally supplement this diet.

Every house has a small flower garden, and many have pet birds, kept in cages (Fig. 7). In the barn of the house we visited, there were curiously shaped offering vessels made of *satogara,* an edible plant, for the popular deity Jizō. *Shōchū,* a rice liquor, is put in them for the Jizō festival once a year.

The morning turned out to be a fine one after the mists rose. We visited a small grass-roofed wayside shrine, or *dō,* for Jizō, who is said to keep disease away from the hamlet. The *dō* also houses the images of three other deities: Kwannon, Shaka, and Daishi—all of them newly gilt. They are celebrated by three groups of eight or nine

FIG. 6. A JAPANESE MOUNTAINEER
LUNCHBOX IN HAND, HE IS ABOUT TO SET OFF FOR A DAY'S WORK ON HIS DISTANT MOUNTAINSIDE FARM.

families, each contributing buckwheat cakes on festival days. The festivals follow the lunar calendar: Jizō the 14th of the sixth month, Kwannon the 15th of the tenth month, and so on. The structure also contained several pictures of the Emperor and Empress and a photograph of Russian and Japanese generals taken ensemble after the fall of Port Arthur. Elsewhere in Japan these pictures are usually found in Shinto shrines rather than in the little Buddhist *dō.*

We also visited the two temples of Kureko. One has a priest, the other not. Certain ceremonies still take place at the latter, however. It is a melancholy place, its old straw roof overgrown with plants. Inside we found the hand fire pump of Kureko, a few books of sutras and a Buddhist statue. The image and other woodwork had been painted, but most of the paint has peeled off from age and lack of care.

We were told that about ten years previ-

ously there had been a fire in which the school burned down as well as one of the temples. In its place a tin-roofed one was erected which is today the only active temple for many miles around. For memorial services a person from another settlement comes here ahead of time to tell the priest to read sutras, then returns home where a banquet for relatives is held. As might be expected in this isolated region the Buddhist priest does a little farming in addition to his priestly duties. Most of the people of Kureko belong to the Shinshū sect of Buddhism.

There is also a Shinto shrine, housing a mountain god, and a Shinto priest. The shrine is new, and like the recently rebuilt temple, it has a tin roof. The annual festival is held on the first of the eighth month, by lunar calendar.

Next we visited an aged man, seventy-seven years old, who used to be *shōya*, or headman, of Kureko, before the new governmental system replaced the feudal one in this region. When we called, we discovered him busy making a basketry bag (Fig. 8). He has a son who is postmaster of the post office in Kobaru.

Our host, the *kuchō*, told us that the *shōya* claims descent from the Heike and has an old sword—but shows it to no one. From the *kuchō's* manner of recounting this he evidently bears the old *shōya* no great love. The *kuchō* says that most people have old swords, but that the old *shōya* is the only man in Kureko who claims descent from the Heike.

The single shop of Kureko was our next stop. We found it in the care of a still older person—a woman of ninety-three. Her family is the same as that of our host's wife. A beautiful girl of fourteen waited on us. She said they sell four or five cans of pineapple a month, mostly to transients such as ourselves. *Sake* is also sold, and dried seaweed. There was one can of beef and a few bottles of beer in stock. Metal tool blades were also for sale; the farmers buy them and make their own handles of wood. The little shop sells neither tobacco nor salt; for these one must go to Miyazono.

FIG. 7. FARM STORAGE UNDER THE EAVES OF A MOUNTAIN COTTAGE

SEED GRAIN AND VEGETABLES ARE HUNG UP TO DRY. NOTE ALSO THE BIRD CAGE, FIREWOOD, AND ODDMENTS.

Money expenses in Kureko are few, mostly

for wine and clothes. All food is homegrown. Labor is exchanged. Cloth is purchased in Miyazono and made into garments by the women.

In the *kuchō's* house are many drums and some hats of cocks' feathers. These are for the Taiko Odori, or Drum Dance (Fig. 9), which is performed three times a year at Bon (the festival of the return of spirits of the dead in mid-July), on August 1 (the day of the Shinto Shrine celebration), and on the last day of autumn Higan (a Buddhist celebration of the autumn equinox). Both the *kuchō* and his son are dancers and members of the dancers' society. Any man may enter this society if he announces his intention at the beginning of the year, but once he has joined, he must perform dances for ever after.

People come to see the Drum Dance from as far away as Mizukami (a village outside Gokkanosho). The drum skins are made of the hide of the wild boar, imported from Nagano prefecture far to the north. They used to use local boar, but this is now extinct. Dances, of which there are many varieties, are performed in the schoolyard.

We began our walk to the next hamlet of Shiibaru amid immense and steep mountains checkered here and there with *koba* where the mountaineers eke out a living. The fields are

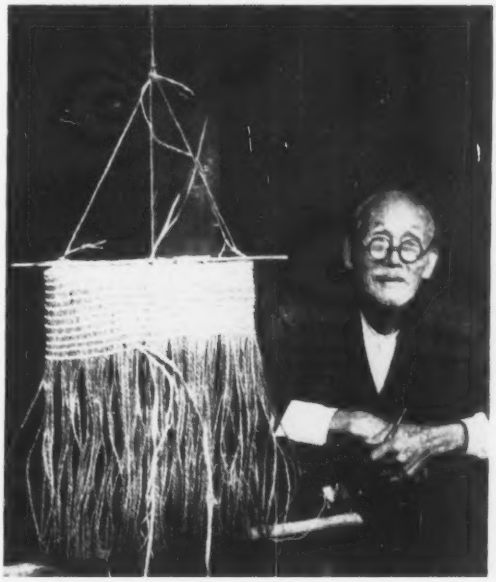


FIG. 8. VENERABLE EX-HEADMAN
MAKES FIBER BAGS, SMOKING A THREE-PUFF PIPE.

on hillsides said to be at an incline of 45° or more. Being 2 or 3 miles distant from home is only half the difficulty of farming them; the steepness of the grade in getting to them is worse. Charcoal workers here send wood down hillsides and across ravines on wires.

We soon met a man making a new clearing. He told us that a tenant such as himself pays as rent one-fifth of the produce of the *koba*

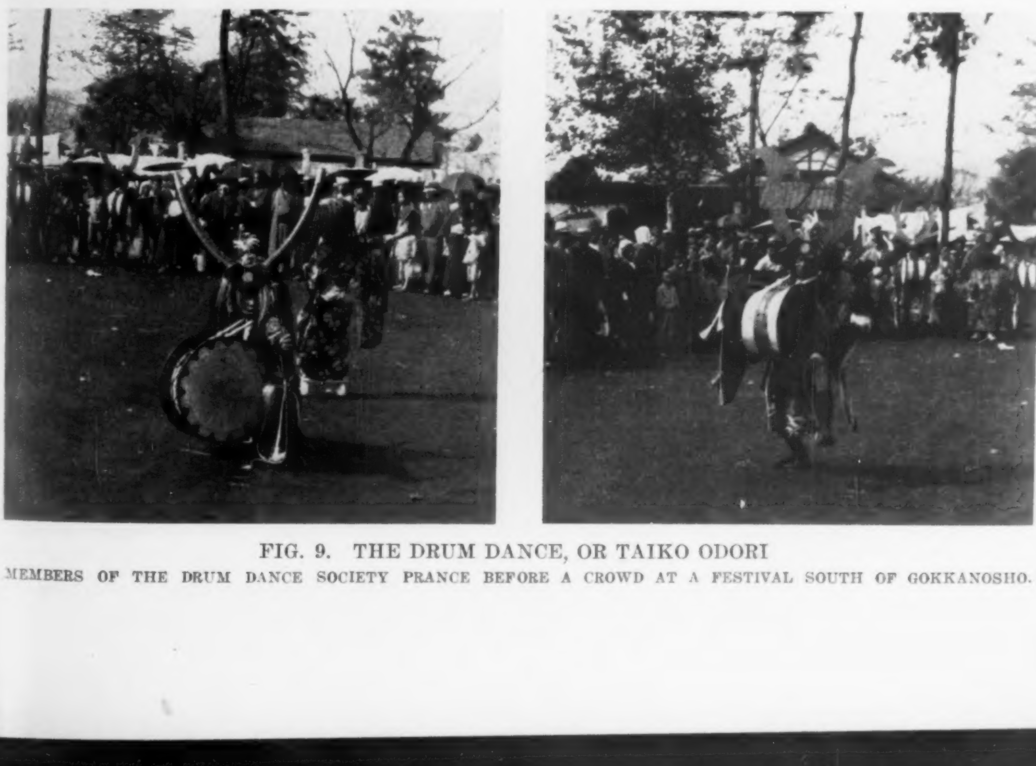


FIG. 9. THE DRUM DANCE, OR TAIKO ODORI
MEMBERS OF THE DRUM DANCE SOCIETY PRANCE BEFORE A CROWD AT A FESTIVAL SOUTH OF GOKKANOSHO.

he cultivates for three years and thereafter may work it free indefinitely. A good *koba* might last seven years. He also told us that our host and his wife of the night before both come from rich families.

Later we met a man from Nitao hamlet on his way to Kureko to tell the priest of a three-year memorial service for his mother. He will spend the night with the priest before returning to Nitao.

After four hours' walk we came to Shiibaru, a beautiful little hamlet of fifteen families (Figs. 10 and 11). Just outside the settlement itself we passed fields with more tea than the usual. Some bushes were scattered amid corn fields, but others were neatly arranged and evidently well cared for, much more so than the wild tea bushes used by the plains people of Kuma.

All the people of Shiibaru claim to be descended from the Heike—every man a *bushi*. The old *shōya's* house was a fine structure, larger and grander than anything in Suye. The house and outbuildings were on a large earth platform sustained by stone embankments. A *shōya's* house in Gokkanosho always stands out. The people here preserve old forms of politeness not found in ordinary rural districts—a part of their pride of ancestry. Even ordinary houses in Shiibaru have gardens of stunted trees, stone walls, and an air of ancient grandeur.

There are no shops in the hamlet and but one inn. We saw a tobacco sign, but no one was home at the house where it was hung. At the inn, really a private house which serves tea and cakes to travellers, we rested and talked with the mistress of the house over our refreshments. We were told that the chief products of the hamlet are tea and mushrooms. We were also told, probably as a boast, that people here often receive wives from big cities such as Osaka and Tokyo. If a man goes on a trip he may bring home a wife from such a large city.

The man of the inn showed us some *montake*, bamboo that has been stained by mold or in some other natural manner in the forest. He said that such bamboo is rare and that it occurs only in Gokkanosho. He sells it. He told us also that the hamlets of Shiibaru, Nitao, and Momigi were under the

FIG. 10. THE APPROACH TO THE HAMLET OF SHIIBARU
THE PATCHES ON THE MOUNTAINSIDE ARE FIELDS, OR *koba*, FROM WHICH THE INHABITANTS EKE A LIVING.

FIG. 11. A CLOSER VIEW OF SHIIBARU
COMPARE THESE NEAT ROOFS WITH THE VERDANT ROOF IN FIG. 4. EACH DISTRICT HAS ITS OWN ROOF TYPE.

Heike while Kureko and Hagi were under Sugawara. This might account for the lack of Heike descendants in Kureko.

Before we left, the woman told us that we might expect a long, steep incline a short distance from the hamlet. Soon we came to a stream of unusual beauty rushing under an old, rotten wooden bridge and on by some black, damp overhanging rocks. The noisy water itself was a mixture of color: white, blue, green, and in dark, deep places, black. Then we came to the sharp ascent. The woman did not exaggerate; it was long, it was rough, and it was steep.

The next hamlet, Kobaru, is a cluster of houses like Shiibaru. Here there is a school, a post office, and a shop. Because of bad water, we did not stop. A little farther on we came to a settlement consisting of one house, called Shimoyashiki (five miles to the east is one of two houses called Furuyashiki). Both these districts form part of Nitao hamlet.

The one house of Shimoyashiki was large and spacious. When we arrived, we found a manservant mending the paper screens. When we inquired concerning lodging for the night, he disappeared into the recesses of the house and soon returned with paper and a request for our names. These were given, and shortly thereafter we were shown to a hot bath in an elegant bathhouse.

The main house was on rather a grand scale; more so than any in Suye, though, unlike Suye, many of the rooms are not occupied. These vacant rooms have no straw mats laid down, but they are put down for guests.

For supper our rice was cooked, and we were given potato and seafish soup. I asked for a cucumber, and soon a small boy came in breathless and held out with his two hands a large and luscious cucumber. Then he rushed out. His polite manner of handing it to us was remarkable, symptomatic of the formal ways of Heike descendants. One young companion from Suye said jokingly that in Suye a boy would hand a cucumber with his foot.

Both before and after dinner, our host came to talk with us. His manners also were marked by polite formality. The dinner

FIG. 12. CARRIERS OF WOOD AND CHARCOAL NEAR IWAOKU
PAID IN CASH, THEY BUY RICE, WHEREAS MOST FARMERS OF THE MOUNTAINS SUBSIST CHIEFLY ON MILLET.

itself was served to us by his wife. The family did not eat with us but in another room by the kitchen at the other end of the house.

We learned from our host, Mr. Zoza Sataro, that each hamlet of Gokkanosho has a council of men called *kukaigin* for administering local school affairs. People pay a tax for local school affairs of about one *yen* fifty in addition to a house tax of less than five *yen* (villages in the plains pay an average of twenty to thirty *yen*). There is in addition a special land tax for large landowners.

He told us also about the political organization of the area (he is himself a village councilor). His grandfather was head of the post office in Kobaru, his great grandfather a *shōya*. He is himself an adopted son. His wife is also from outside the family. The important thing is the house and the name; the individuals merely carry it on.

There is no true Shinto priest in Gokkanosho. Instead, one in Kakisako is hired once a year for the shrine festival. The one mentioned in Kureko, it seems, is not an orthodox one. There is, however, a Shinto shrine (*sonsha*) in each hamlet of Gokkanosho.

As he talked he held the small boy in his lap and eventually the child fell asleep. Other children occasionally peeked in but were reprimanded by their father. There was much more formality in this household than in that of the *kuchō* at Kureko.

In the morning, as at Kureko, we awoke to a cool mist, the sound of a mountain stream, and the view of high mountains.

After a breakfast of lukewarm rice, our hostess brought us rice balls wrapped in bamboo shoot sheaths to serve for our lunch. Taking our leave at nine o'clock, we walked fairly constantly for three hours through forests, along steep rocky hillsides with here and there a *koba*, those remarkable fields where people grow crops out of nothing.

When not far from Iwaoku, a settlement beyond old Gokkanosho, we met a family of carriers well loaded down with wood. They said they receive 35 *sen* for each sack of charcoal and 50 *sen* for each bundle of wood for tubs. They make one trip of about three miles a day (Fig. 12). With the money they buy rice and thus have a different diet from

the farmers of the mountains who eat only millet and wheat, both regarded as much inferior to rice. While the trip is comparatively short, it is very hilly and the loads extremely heavy.

Soon we met other carriers and hikers and so could tell we were coming closer to civilization. Finally we came to the top of a high ridge and there, suddenly, we came upon an immense panorama of hills and valleys in the foreground with the sea visible in the far distance.

As we descended the path on the other side and eventually approached Iwaoku, the hillsides were broken into terraces, the high ones for sweet potatoes, millet, etc., the lower ones for rice. Tiger lilies grew near the potato patches, the root being considered good to eat.

The little village of Iwaoku is where the road to Yatsushiro town begins. Here are shops, rice wine, and various evidences of a typical village. Here many people from Gokkanosho come for supplies and from here wagoners take lumber down to the towns. We saw several wagoners busy drinking.

As there was no bus here, we had to walk on a couple of miles farther. Finally we came to Kayaba where there is a school. By the side of the road at the entrance were images of Jizō, Daiishi, and a Sarutahiko stone all in a row, so the place was well protected.

But Kayaba, like Iwoaka, had no bus service. We walked on again, feeling very tired and finally came to Futae where at last we found a bus station and what was more, a bus was due in twenty minutes. So we sat down to a late and hasty lunch.

The bus proved to be a 1931 Ford touring car. We, and one other man climbed in. The bus took us to Arisa, north of Yatsushiro, just in time for the train to Hitoyoshi and thence back to Suye. And so we returned to our home in the ordinary but familiar rice village of Suye Mura. When we met people on the road the next day, they bowed, saying, "You have had a long trip, are you not tired?"

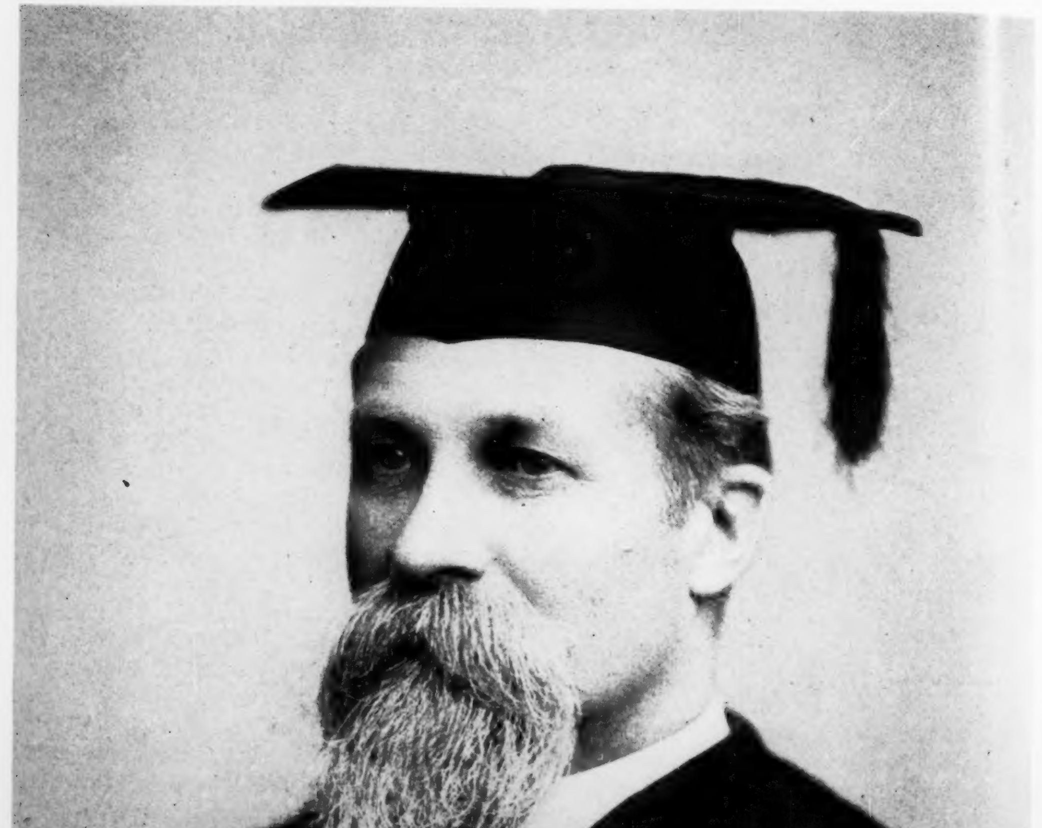
In conclusion I should like to make a few general remarks about this interesting old region of Japan. One striking thing about the settlement is the number of fine dwellings. Another is the apparent similarity of daily life here with that of old Japan. However, we found no examples of the big family households of several brothers and their wives and children under one roof as some people had reported to us before our trip through Gokkanosho.

There are certain customs in striking contrast to the relatively nearby area of Kuma, such as relatives instead of neighbors acting as pallbearers at a funeral. The economic life is also rather different from ordinary Japanese villages. The communities are pretty well self-sustaining, depending for food on millet and potatoes instead of rice, and the cash income is from lumber and mushrooms instead of silk and rice. Whereas rice sometimes still serves as a medium of exchange in certain intravillage affairs in the plains, in Gokkanosho the *azuki* bean is used.

Electricity and gas engines, common in rural Japan today, are quite absent from Gokkanosho.

There is considerable variety between the hamlets. In Kureko, for instance, the people do not claim Heike descent, and the houses are for the most part unimposing and scattered geographically. All marriages are said to take place within the village. Shiibaru, on the other hand, claims noble descent from the Heike, wives frequently come from outside, and the beautiful houses and gardens form a compact cluster. The Kureko *kuchō* says that the people of Hagi do much drinking, those of Kureko little. If true, why? A profitable social study could be made of life in these various mountain settlements.

Gokkanosho is still an isolated region, an area of old folk culture. Since my visit I have read that there are plans to build over a period of five years a road through the region for carrying out timber. Since the war began this may have been completed, thus removing some of the isolation of the mountain hamlets. The basic economy and general way of life, however, doubtless remain much the same today as they were six years ago.



T. C. CHAMBERLIN, 1843–1928

THE METHOD OF MULTIPLE WORKING HYPOTHESES*

By T. C. CHAMBERLIN

THERE are two fundamental modes of study. The one is an attempt to follow by close imitation the processes of previous thinkers and to acquire the results of their investigations by memorizing. It is study of a merely secondary, imitative, or acquisitive nature. In the other mode the effort is to think independently, or at least individually. It is primary or creative study. The endeavor is to discover new truth or to make a new combination of truth or at least to develop by one's own effort an individualized assemblage of truth. The endeavor is to think for one's self, whether the thinking lies wholly in the fields of previous thought or not. It is not necessary to this mode of study that the subject matter should be new. Old material may be reworked. But it is essential that the process of thought and its results be individual and independent, not the mere following of previous lines of thought ending in predetermined results. The demonstration of a problem in Euclid precisely as laid down is an illustration of the former, the demonstration of the same proposition by a method of one's own or in a manner distinctively individual is an illustration of the latter, both lying entirely within the realm of the known and old.

Creative study, however, finds its largest application in those subjects in which, while much is known, more remains to be learned. The geological field is pre-eminently full of such subjects; indeed, it presents few of any other class. There is probably no field of thought which is not sufficiently rich in such subjects to give full play to investigative modes of study.

Three phases of mental procedure have been prominent in the history of intellectual evolution thus far. What additional phases may be in store for us in the evolutions of the future it may not be prudent to attempt to forecast. These three phases may be styled "the method of the ruling theory," "the method of the working hypothesis," and "the method of multiple working hypotheses."

In the earlier days of intellectual development the sphere of knowledge was limited and could be brought much more nearly than now within the compass of a single individual. As a natural result those who then assumed to be wise men, or aspired to be thought so, felt the need of knowing, or at least seeming to know, all that was known, as a justification of their claims. So also as a natural counterpart there grew up an expectancy on the part of the multitude that the wise and the learned would explain whatever new thing presented itself. Thus pride and ambition on the one side and expectancy on the other joined hands in developing the putative all-wise man whose knowledge boxed the compass and whose acumen found an explanation for every new puzzle which presented itself. Although the pretended compassing of the entire horizon of knowledge has long since become an abandoned affectation, it has left its representatives in certain intellectual predilections. As in the earlier days, so still, it is a too frequent habit to hastily conjure up an explanation for every new phenomenon that presents itself. Interpretation leaves its proper place at the end of the intellectual procession and rushes to the forefront. Too often a theory is promptly

* Professor T. C. Chamberlin of the University of Chicago, who died in 1928, was a famous geologist and a former president of the American Association for the Advancement of Science. He was noted for his rigorous application of the scientific method. In 1897 he published in the *Journal of Geology* (vol. 5, pp. 837–848) the paper that is here reprinted with permission of the University of Chicago Press. Because the demand for it continued through the years, it was reprinted in 1931 in the *Journal of Geology* (vol. 39, pp. 155–165). Such evidence of the importance of this essay to geologists suggested that it should be made available to other scientists, all of whom should be acquainted with "The Method of Multiple Working Hypotheses." Grateful acknowledgment is made to Professor R. T. Chamberlin for making arrangements for the reprinting of this article and for supplying the portrait of his father, at age 49, shown on the opposite page.—Eds.

born and evidence hunted up to fit it afterward. Laudable as the effort at explanation is in its proper place, it is an almost certain source of confusion and error when it runs before a serious inquiry into the phenomenon itself. A strenuous endeavor to find out precisely what the phenomenon really is should take the lead and crowd back the question, commendable at a later stage, "How came this so?" First the full facts, then the interpretation thereof, is the normal order.

The habit of precipitate explanation leads rapidly on to the birth of general theories.[1] When once an explanation or special theory has been offered for a given phenomenon, self-consistency prompts to the offering of the same explanation or theory for like phenomena when they present themselves, and there is soon developed a general theory explanatory of a large class of phenomena similar to the original one. In support of the general theory there may not be any further evidence or investigation than was involved in the first hasty conclusion. But the repetition of its application to new phenomena, though of the same kind, leads the mind insidiously into the delusion that the theory has been strengthened by additional facts. A thousand applications of the supposed principle of levity to the explanation of ascending bodies brought no increase of evidence that it was the true theory of the phenomena; but it doubtless created the impression in the minds of ancient physical philosophers that it did, for so many additional facts seemed to harmonize with it.

For a time these hastily born theories are likely to be held in a tentative way with some measure of candor or at least some self-illusion of candor. With this tentative spirit and measurable candor, the mind satisfies its moral sense and deceives itself with the thought that it is proceeding cautiously and impartially toward the goal of ultimate truth. It fails to recognize that no amount of provisional holding of a theory, no amount of application of the theory, so long as the study lacks in incisiveness and exhaustiveness, justifies an ultimate conviction. It is not the slowness with which conclusions are arrived at that should give satisfaction to the moral sense, but the precision, the completeness and the impartiality of the investigation.

It is in this tentative stage that the affections enter with their blinding influence. Love was long since discerned to be blind, and what is true in the personal realm is measurably true in the intellectual realm. Important as the intellectual affections are as stimuli and as rewards, they are nevertheless dangerous factors in research. All too often they put under strain the integrity of the intellectual processes. The moment one has offered an original explanation for a phenomenon which seems satisfactory, that moment affection for his intellectual child springs into existence; and as the explanation grows into a definite theory, his parental affections cluster about his offspring and it grows more and more dear to him. While he persuades himself that he holds it still as tentative, it is none the less lovingly tentative and not impartially and indifferently tentative. So soon as this parental affection takes possession of the mind, there is apt to be a rapid passage to the unreserved adoption of the theory. There is then imminent danger of an unconscious selection and of a magnifying of phenomena that fall into harmony with the theory and support it and an unconscious neglect of phenomena that fail of coincidence. The mind lingers with pleasure upon the facts that fall happily into the embrace of the theory, and feels a natural coldness toward those that assume a refractory attitude. Instinctively, there is a special searching-out of phenomena that support it, for the mind is led by its desires. There springs up also unwittingly a pressing of the theory to make it fit the facts and a pressing of the facts to make them fit the theory. When these biasing tendencies set in, the mind rapidly degenerates into the partiality of paternalism. The search for facts, the observation of phenomena, and their interpretation are all dominated by affection for the favored theory until it appears to its

[1] I use the term "theory" here instead of hypothesis because the latter is associated with a better controlled and more circumspect habit of the mind. This restrained habit leads to the use of the less assertive term "hypothesis," while the mind in the habit here sketched more often believes itself to have reached the higher ground of a theory and more often employs the term "theory." Historically also, I believe the word "theory" was the term commonly used at the time this method was predominant.

author or its advocate to have been overwhelmingly established. The theory then rapidly rises to a position of control in the processes of the mind and observation; induction and interpretation are guided by it. From an unduly favored child it readily grows to be a master and leads its author whithersoever it will. The subsequent history of that mind in respect to that theme is but the progressive dominance of a ruling idea. Briefly summed up, the evolution is this: a premature explanation passes first into a tentative theory, then into an adopted theory, and lastly into a ruling theory.

When this last stage has been reached, unless the theory happens perchance to be the true one, all hope of the best results is gone. To be sure, truth may be brought forth by an investigator dominated by a false ruling idea. His very errors may indeed stimulate investigation on the part of others. But the condition is scarcely the less unfortunate.

As previously implied, the method of the ruling theory occupied a chief place during the infancy of investigation. It is an expression of a more or less infantile condition of the mind. I believe it is an accepted generalization that in the earlier stages of development the feelings and impulses are relatively stronger than in later stages.

Unfortunately the method did not wholly pass away with the infancy of investigation. It has lingered on, and reappears in not a few individual instances at the present time. It finds illustration in quarters where its dominance is quite unsuspected by those most concerned.

The defects of the method are obvious and its errors grave. If one were to name the central psychological fault, it might be stated as the admission of intellectual affection to the place that should be dominated by impartial, intellectual rectitude alone.

So long as intellectual interest dealt chiefly with the intangible, so long it was possible for this habit of thought to survive and to maintain its dominance, because the phenomena themselves, being largely subjective, were plastic in the hands of the ruling idea; but so soon as investigation turned itself earnestly to an inquiry into natural phenomena whose manifestations are tangible, whose properties are inflexible, and whose laws are rigorous, the defects of the method became manifest and an effort at reformation ensued. The first great endeavor was repressive. The advocates of reform insisted that theorizing should be restrained and the simple determination of facts should take its place. The effort was to make scientific study statistical instead of causal. Because theorizing in narrow lines had led to manifest evils, theorizing was to be condemned. The reformation urged was not the proper control and utilization of theoretical effort but its suppression. We do not need to go backward more than a very few decades to find ourselves in the midst of this attempted reformation. Its weakness lay in its narrowness and its restrictiveness. There is no nobler aspiration of the human intellect than the desire to compass the causes of things. The disposition to find explanations and to develop theories is laudable in itself. It is only its ill-placed use and its abuse that are reprehensible. The vitality of study quickly disappears when the object sought is a mere collocation of unmeaning facts.

The inefficiency of this simply repressive reformation becoming apparent, improvement was sought in the method of the working hypothesis. This has been affirmed to be *the* scientific method. But it is rash to assume that any method is *the* method, at least that it is the ultimate method. The working hypothesis differs from the ruling theory in that it is used as a means of determining facts rather than as a proposition to be established. It has for its chief function the suggestion and guidance of lines of inquiry—the inquiry being made, not for the sake of the hypothesis, but for the sake of the facts and their elucidation. The hypothesis is a mode rather than an end. Under the ruling theory, the stimulus is directed to the finding of facts for the support of the theory. Under the working hypothesis, the facts are sought for the purpose of ultimate induction and demonstration, the hypothesis being but a means for the more ready development of facts and their relations.

It will be observed that the distinction is not such as to prevent a working hypothesis from gliding with the utmost ease into a ruling theory. Affection may as easily cling

about a beloved intellectual child when named a "hypothesis" as if named a "theory," and its establishment in the one guise may become a ruling passion very much as in the other. The historical antecedents and the moral atmosphere associated with the working hypothesis lend some good influence, however, toward the preservation of its integrity.

Conscientiously followed, the method of the working hypothesis is an incalculable advance upon the method of the ruling theory, but it has some serious defects. One of these takes concrete form, as just noted, in the ease with which the hypothesis becomes a controlling idea. To avoid this grave danger, the method of multiple working hypotheses is urged. It differs from the simple working hypothesis in that it distributes the effort and divides the affections. It is thus in some measure protected against the radical defect of the two other methods. In developing the multiple hypotheses, the effort is to bring up into view every rational explanation of the phenomenon in hand and to develop every tenable hypothesis relative to its nature, cause, or origin, and to give to all of these as impartially as possible a working form and a due place in the investigation. The investigator thus becomes the parent of a family of hypotheses; and by his parental relations to all is morally forbidden to fasten his affections unduly upon any one. In the very nature of the case, the chief danger that springs from affection is counteracted. Where some of the hypotheses have been already proposed and used, while others are the investigator's own creation, a natural difficulty arises; but the right use of the method requires the impartial adoption of all alike into the working family. The investigator thus at the outset puts himself in cordial sympathy and in parental relations (of adoption, if not of authorship) with every hypothesis that is at all applicable to the case under investigation. Having thus neutralized, so far as may be, the partialities of his emotional nature, he proceeds with a certain natural and enforced erectness of mental attitude to the inquiry, knowing well that some of his intellectual children (by birth or adoption) must needs perish before maturity, but yet with the hope that several of them may survive the ordeal of crucial research, since it often proves in the end that several agencies were conjoined in the production of the phenomena. Honors must often be divided between hypotheses. One of the superiorities of multiple hypotheses as a working mode lies just here. In following a single hypothesis, the mind is biased by the presumptions of its method toward a single explanatory conception. But an adequate explanation often involves the co-ordination of several causes. This is especially true when the research deals with a class of complicated phenomena naturally associated but not necessarily of the same origin and nature, as, for example, the Basement complex or the Pleistocene drift. Several agencies may not only participate but their proportions and importance may vary from instance to instance in the same field. The true explanation is therefore necessarily complex, and the elements of the complex are constantly varying. Such distributive explanations of phenomena are especially contemplated and encouraged by the method of multiple hypotheses and constitute one of its chief merits. For many reasons we are prone to refer phenomena to a single cause. It naturally follows that when we find an effective agency present, we are predisposed to be satisfied therewith. We are thus easily led to stop short of full results, sometimes short of the chief factors. The factor we find may not even be the dominant one, much less the full complement of agencies engaged in the accomplishment of the total phenomena under inquiry. The mooted question of the origin of the Great Lake basins may serve as an illustration. Several hypotheses have been urged by as many different students of the problem as the cause of these great excavations. All of these have been pressed with great force and with an admirable array of facts. Up to a certain point we are compelled to go with each advocate. It is practically demonstrable that these basins were river valleys antecedent to the glacial incursion. It is equally demonstrable that there was a blocking-up of outlets. We must conclude then that the present basins owe their origin in part to the pre-existence of river valleys and to the blocking-up of their outlets by drift. That there is a temptation to rest here, the history of the question shows. But

on the other hand, it is demonstrable that these basins were occupied by great lobes of ice and were important channels of glacial movement. The leeward drift shows much material derived from their bottoms. We cannot therefore refuse assent to the doctrine that the basins owe something to glacial excavation. Still again it has been urged that the earth's crust beneath these basins was flexed downward by the weight of the ice load and contracted by its low temperature and that the basins owe something to crustal deformation. This third cause tallies with certain features not readily explained by the others. And still it is doubtful whether all these combined constitute an adequate explanation of the phenomena. Certain it is, at least, that the measure of participation of each must be determined before a satisfactory elucidation can be reached. The full solution therefore involves not only the recognition of multiple participation but an estimate of the measure and mode of each participation. For this the simultaneous use of a full staff of working hypotheses is demanded. The method of the single working hypothesis or the predominant working hypothesis is incompetent.

In practice it is not always possible to give all hypotheses like places, nor does the method contemplate precisely equable treatment. In forming specific plans for field, office, or laboratory work, it may often be necessary to follow the lines of inquiry suggested by some one hypothesis rather than those of another. The favored hypothesis may derive some advantage therefrom or go to an earlier death, as the case may be, but this is rather a matter of executive detail than of principle.

A special merit of the use of a full staff of hypotheses co-ordinately is that in the very nature of the case it invites thoroughness. The value of a working hypothesis lies largely in the significance it gives to phenomena which might otherwise be meaningless and in the new lines of inquiry which spring from the suggestions called forth by the significance thus disclosed. Facts that are trivial in themselves are brought forth into importance by the revelation of their bearings upon the hypothesis and the elucidation sought through the hypothesis. The phenomenal influence which the Darwinian hypothesis has exerted upon the investigations of the past two decades is a monumental illustration. But while a single working hypothesis may lead investigation very effectively along a given line, it may in that very fact invite the neglect of other lines equally important. Very many biologists would doubtless be disposed today to cite the hypothesis of natural selection, extraordinary as its influence for good has been, as an illustration of this. While inquiry is thus promoted in certain quarters, the lack of balance and completeness gives unsymmetrical and imperfect results. But if, on the contrary, all rational hypotheses bearing on a subject are worked co-ordinately, thoroughness, equipoise, and symmetry are the presumptive results in the very nature of the case.

In the use of the multiple method, the reaction of one hypothesis upon another tends to amplify the recognized scope of each. Every hypothesis is quite sure to call forth into clear recognition new or neglected aspects of the phenomena in its own interests, but ofttimes these are found to be important contributions to the full deployment of other hypotheses. The eloquent expositions of "prophetic" characters at the hands of Agassiz were profoundly suggestive and helpful in the explication of "undifferentiated" types in the hand of the evolutionary theory.

So also the mutual conflicts of hypotheses whet the discriminative edge of each. The keenness of the analytic process advocates the closeness of differentiating criteria, and the sharpness of discrimination is promoted by the co-ordinate working of several competitive hypotheses.

Fertility in processes is also a natural sequence. Each hypothesis suggests its own criteria, its own means of proof, its own method of developing the truth; and if a group of hypotheses encompass the subject on all sides, the total outcome of means and of methods is full and rich.

The loyal pursuit of the method for a period of years leads to certain distinctive habits of mind which deserve more than the passing notice which alone can be given them here. As a factor in education, the disciplinary value of the method is one of prime importance. When faithfully followed for a sufficient time, it develops a mode of thought

of its own kind which may be designated "the habit of parallel thought," or "of complex thought." It is contradistinguished from the linear order of thought which is necessarily cultivated in language and mathematics because their modes are linear and successive. The procedure is complex and largely simultaneously complex. The mind appears to become possessed of the power of simultaneous vision from different points of view. The power of viewing phenomena analytically and synthetically at the same time appears to be gained. It is not altogether unlike the intellectual procedure in the study of a landscape. From every quarter of the broad area of the landscape there come into the mind myriads of lines of potential intelligence which are received and co-ordinated simultaneously, producing a complex impression which is recorded and studied directly in its complexity. If the landscape is to be delineated in language, it must be taken part by part in linear succession.

Over against the great value of this power of thinking in complexes there is an unavoidable disadvantage. No good thing is without its drawbacks. It is obvious, upon studious consideration, that a complex or parallel method of thought cannot be rendered into verbal expression directly and immediately as it takes place. We cannot put into words more than a single line of thought at the same time, and even in that the order of expression must be conformed to the idiosyncrasies of the language. Moreover, the rate must be incalculably slower than the mental process. When the habit of complex or parallel thought is not highly developed, there is usually a leading line of thought to which the others are subordinate. Following this leading line the difficulty of expression does not rise to serious proportions. But when the method of simultaneous mental action along different lines is so highly developed that the thoughts running in different channels are nearly equivalent, there is an obvious embarrassment in making a selection for verbal expression, and there arises a disinclination to make the attempt. Furthermore, the impossibility of expressing the mental operation in words leads to their disuse in the silent processes of thought; and hence words and thoughts lose that close association which they are accustomed to maintain with those whose silent as well as spoken thoughts predominantly run in linear verbal courses. There is therefore a certain predisposition on the part of the practitioner of this method to taciturnity. The remedy obviously lies in co-ordinate literary work.

An infelicity also seems to attend the use of the method with young students. It is far easier, and apparently in general more interesting, for those of limited training and maturity to accept a simple interpretation or a single theory and to give it wide application, than to recognize several concurrent factors and to evaluate these as the true elucidation often requires. Recalling again for illustration the problem of the Great Lake basins, it is more to the immature taste to be taught that these were scooped out by the mighty power of the great glaciers than to be urged to conceive of three or more great agencies working successively in part and simultaneously in part and to endeavor to estimate the fraction of the total results which was accomplished by each of these agencies. The complex and the quantitative do not fascinate the young student as they do the veteran investigator.

The studies of the geologist are peculiarly complex. It is rare that his problem is a simple unitary phenomenon explicable by a single simple cause. Even when it happens to be so in a given instance, or at a given stage of work, the subject is quite sure, if pursued broadly, to grade into some complication or undergo some transition. He must therefore ever be on the alert for mutations and for the insidious entrance of new factors. If, therefore, there are any advantages in any field in being armed with a full panoply of working hypotheses and in habitually employing them, it is doubtless the field of the geologist.

WHEN AMERICAN SEASONS BEGIN

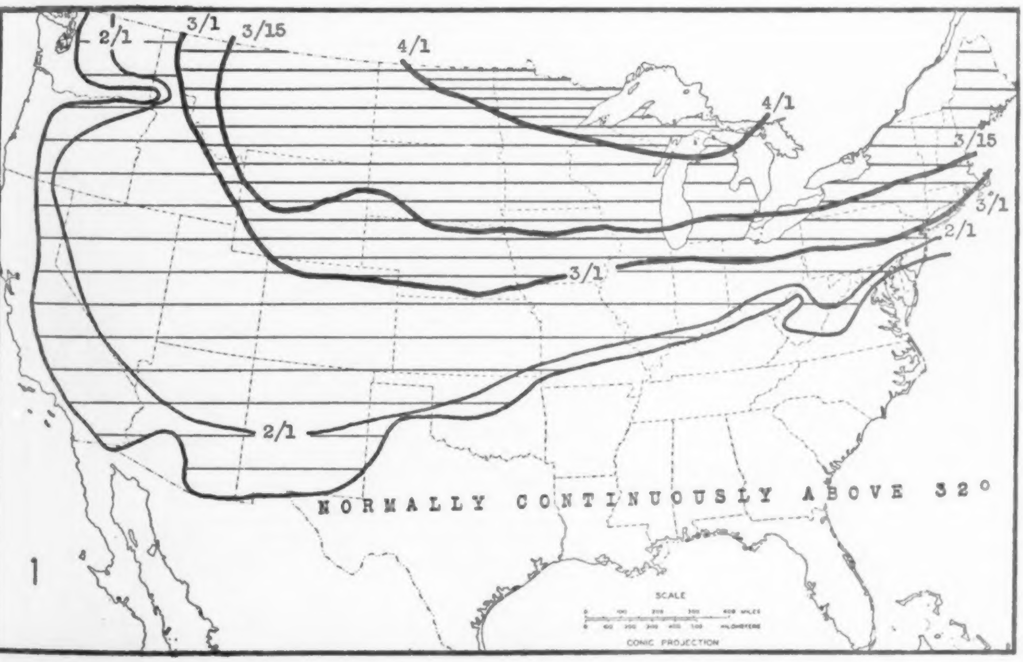
By STEPHEN S. VISHER

THE four chief seasons are popularly announced as commencing with dates of astronomic origin: spring with the vernal equinox, summer with the summer solstice, winter with the shortest day in the year, the winter solstice. But despite the convenience of such preciseness, the fact is that the seasons do not commence on those days in more than a small part of the country. Moreover, the climatic diversity is so great within the United States that the seasons which do occur are not everywhere comparable. Indeed much of the country has six rather than four seasons; two types of summer and two types of winter can readily be recognized on the basis of temperatures alone. In addition, there are seasonal contrasts in the amount and type of precipitation. For example, the wet season and the dry one are more distinct and significant on much of the Pacific Coast than are seasons based on temperatures.

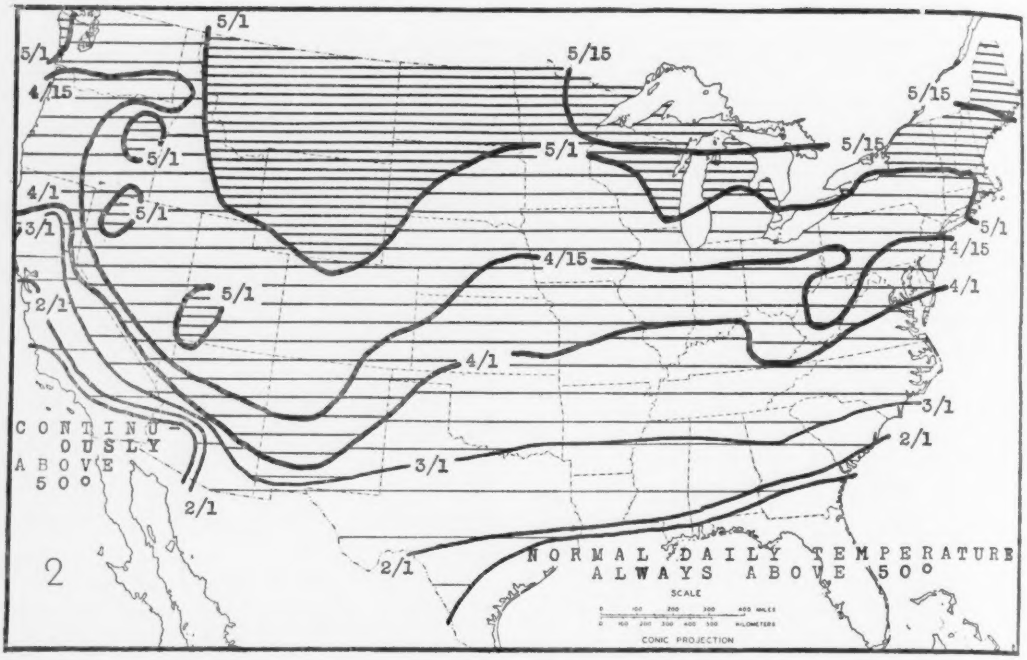
The present article presents nine original maps showing the dates of the beginning of various temperature seasons. The data upon which they are based are the official computations of the daily normal temperatures, the average of day and night, for a 46-year period for 160 well-distributed Weather Bureau Stations (*Monthly Weather Review*, Supplement No. 25).

The temperature limits selected to indicate the dates of the beginning of the seasons are those which seem appropriate, according to common opinion. However, as agreement is incomplete, alternative limits are presented in some instances.

When does spring come? According to one concept, it comes when winter ends, and as any period that has an average of day and night temperature below freezing surely is winter, spring can be said to commence when the daily normal temperature rises above 32° F. Map 1 shows that on this basis spring comes about February 1 along a line extending from Washington, D. C., to central New

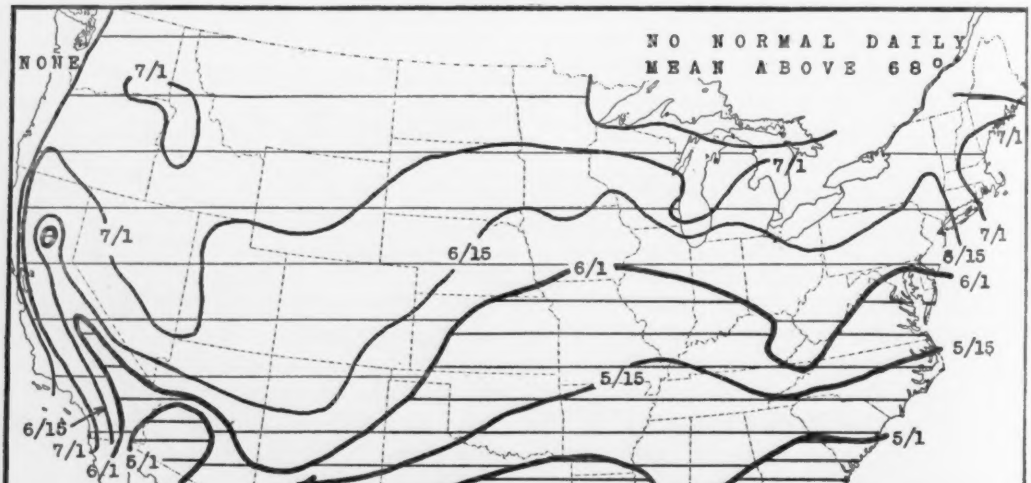


MAP 1. SPRING BEGINS (DATES WHEN DAILY NORMALS RISE ABOVE 32° F.)

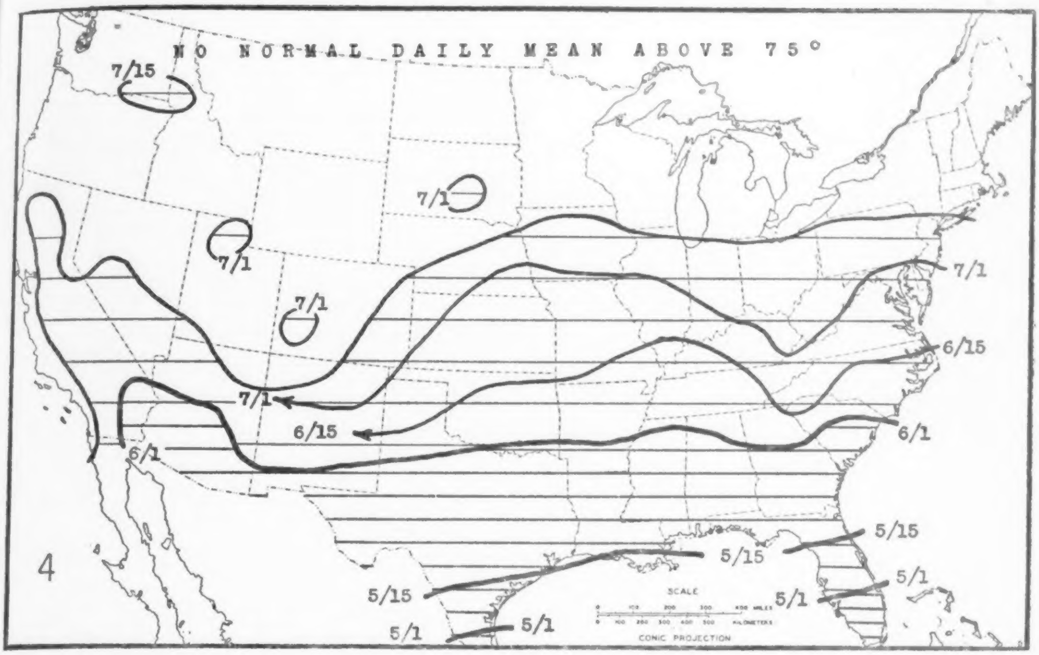


MAP 2. MILD SPRING BEGINS (DATES WHEN DAILY NORMALS RISE ABOVE 50° F.)

Mexico. It comes about March 1 along a line extending from Boston and New York almost due west to northern Colorado. It commences about April 1 in northern Michigan and northern North Dakota. In the South and near the Pacific Ocean, no daily normal is below freezing, and hence winter temperatures normally are lacking, although they



MAP 3. SUMMER BEGINS (DATES WHEN DAILY NORMALS REACH 68° F.)

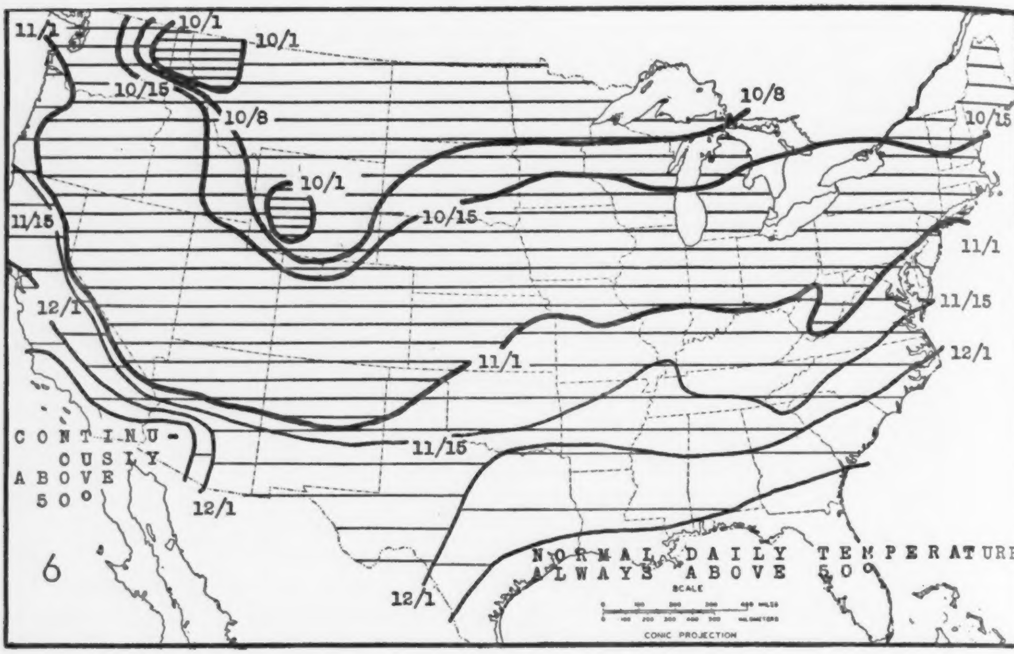


MAP 4. HOT SUMMER BEGINS (DATES WHEN DAILY NORMALS REACH 75° F.)

occur in occasional cold spells. Thus for those sections the beginning of spring as here defined is not indicated on this map.

When the average temperature of day and night together rises slightly above the freezing point, spring has barely commenced. A daily normal temperature of 50° is much more comfortable. Map 2 shows the dates

MAP 5. INDIAN SUMMER BEGINS (DATES WHEN DAILY NORMALS FALL BELOW 68° F.)



MAP 6. COOL FALL BEGINS (DATES WHEN DAILY NORMALS FALL BELOW 50° F.)

when 50° usually is attained. The arrival dates of this degree of warmth correspond more truly with the popular concept of the coming of spring than those shown in Map 1. Map 2 shows that on this basis mild spring temperatures usually commence about February 1 near the Gulf of Mexico and in southwestern California, about April 7 at Washington, D. C., and in central Illinois, and on May 1 or later in the northern states.

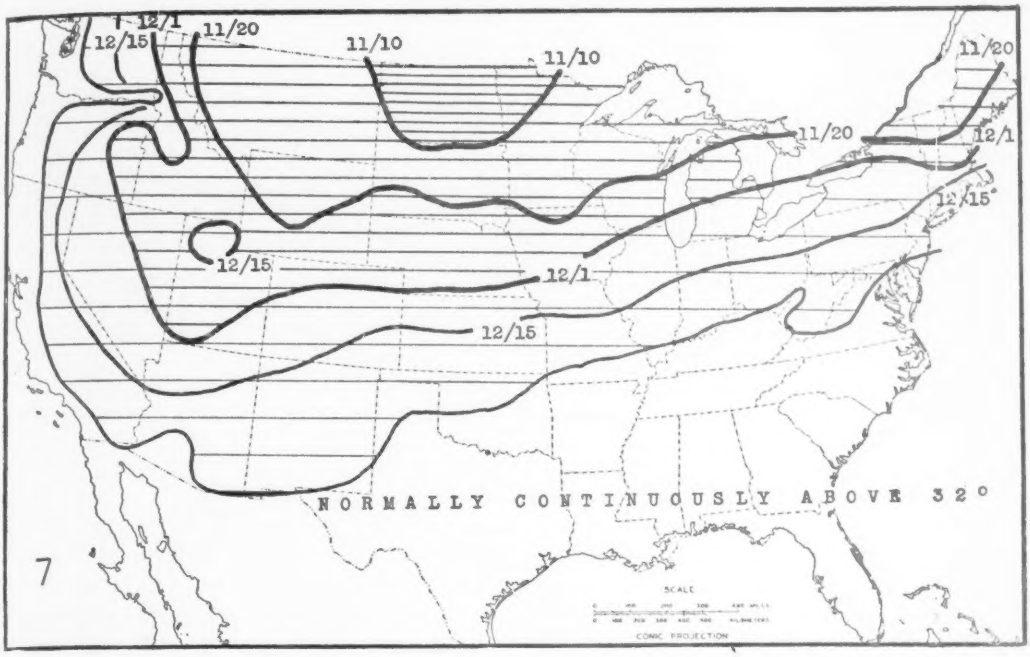
The conventional summer temperature begins with 68°. Map 3 shows that daily normals of 68° prevail even in March in southern Florida, and in April in a rather wide southern zone. They do not extend as far north as Washington, D. C., and central Illinois, however, until June. They never occur close to the Pacific Ocean and Lake Superior or upon the higher mountains.

Although 68° is always called a summer temperature, it represents a fairly mild sort of summer. Daily normals above 75° occur in more than half of the country. The normal dates of arrival of this hot summer condition, shown in Map 4, supplements Map 3 significantly. An average temperature of day and night together of 75° is about 10° above that optimum for human activity, according to extended studies by Ellsworth Huntington and several other investigators. This depressing heat is normally attained, according to Map 4, before June 1 in much of the South and during June in a zone some 400 miles wide extending from New Jersey and North Carolina to the Great Plains. Such high normals are almost lacking, however, in the northern part of the country.

Indian summer comes during the period following summer when the daily normal temperatures are between 68° and 50°. Map 5 shows that regular summer temperatures normally cease by September in the North and during October in the South. Thus Indian summer may be said to commence on the dates shown in Map 5.

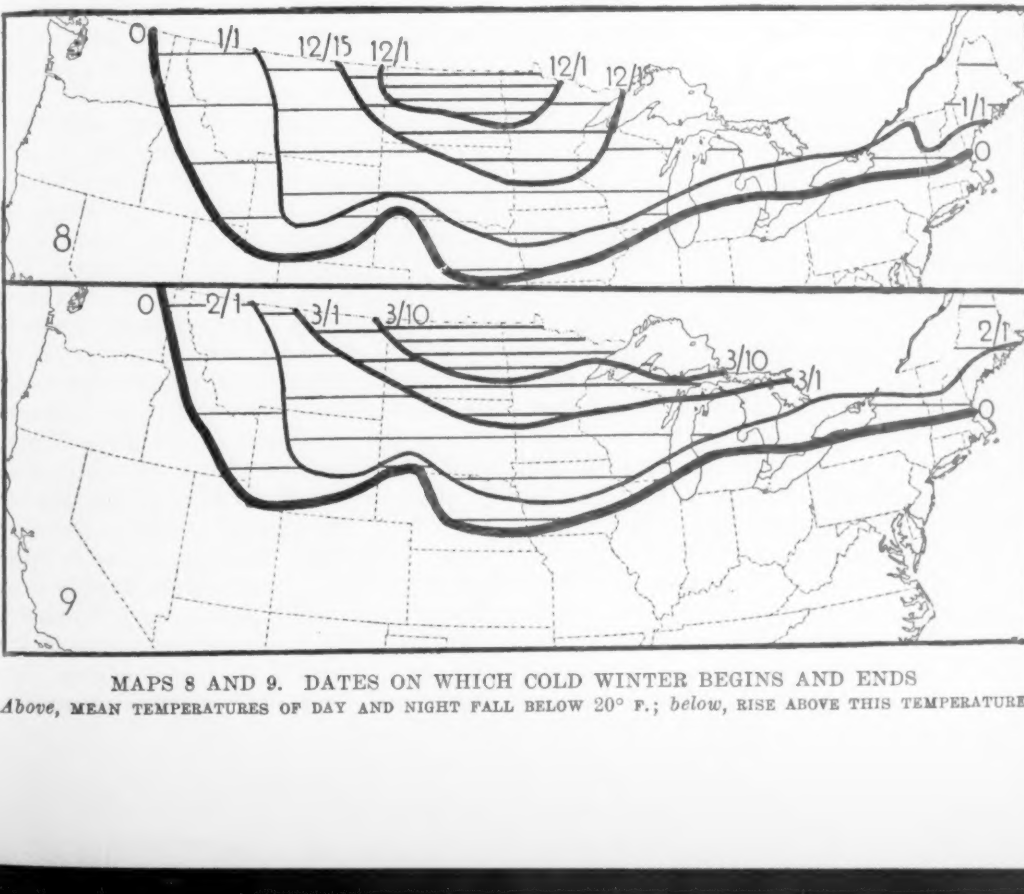
If autumn is the period during which daily normals are between 50° and 32°, it commences in October in the North, in November in the middle zone, and in December in a southern belt. Close to the Gulf of Mexico, however, daily normals are continually above 50° and hence that area, as well as a part of southwestern California, normally lacks autumn coolness (Map 6).

Winter commences, if daily normals below 32° indicate winter, in November in a con-



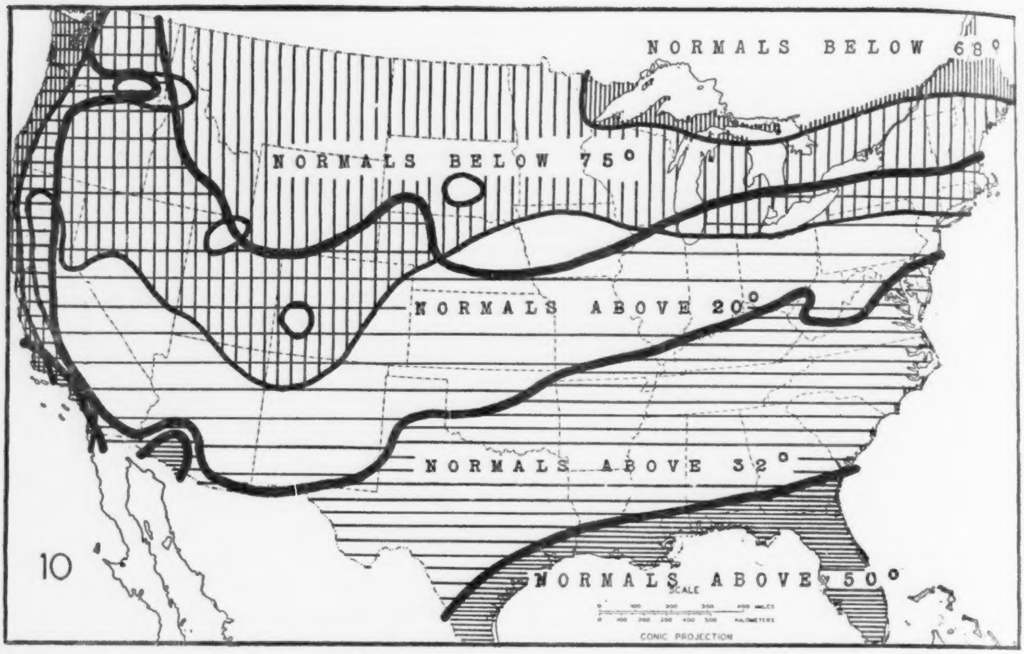
MAP 7. WINTER BEGINS (DATES WHEN DAILY NORMALS FALL BELOW 32° F.)

siderable northern zone, but not at all in a large southern region and also near the Pacific Ocean. Of course the South, even southern Florida, occasionally has freezing temperatures, but without winter as here defined (Map 7).



MAPS 8 AND 9. DATES ON WHICH COLD WINTER BEGINS AND ENDS

Above, MEAN TEMPERATURES OF DAY AND NIGHT FALL BELOW 20° F.; *below,* RISE ABOVE THIS TEMPERATURE.



MAP 10. SEASONAL ZONES BASED ON DAILY NORMAL TEMPERATURES

Maps 8 and 9 are placed together because both concern only the northern half of the country. Cold winter temperatures, here defined as daily normals of 20°, commence shortly before December 1 in the coldest part of the country and in December throughout a considerable northern zone (Map 8). They terminate, Map 9 shows, by February 1 in the southern margin of that belt, and during the first half of March in the northern section. The daily normals in the coldest part of that northern region descend to nearly zero for a few days.

The number of days of each year having daily normal temperatures of each of the types here considered may advantageously be briefly stated. Winter (normals below 32°) is lacking in about a third of the country, but in a large northern area it prevails more than a third of the year. Cool spring-fall (32°–50°) prevails for about four months (about two months in the spring and two in the fall) in a narrow, somewhat central zone, from which zone it decreases gradually northward and sharply southward. Such cool temperatures prevail for five or six months in much of Washington and Oregon and about five months in a belt from New Jersey to central Kentucky. Warm weather (50°–68°) prevails less than 100 days in a year in a large central area from which it increases in all directions. The Pacific Coast has the greatest number of such days, much of coastal California having more than 300 per year. New England has about 135 such days and the extreme Southeast and Gulf Coast and Florida have from 130 to 180. Summer (68° or higher) prevails more than half of the year near the Gulf but is lacking on the Pacific coast north of southern California and in three northern areas, the largest of which is in the Upper Great Lakes. Very hot weather (during which the normals—average of day and night—are 75° or higher) are lacking at the north and along the Pacific Coast, but prevail about a third of the year or longer in the Deep South. Cold winter (normals below 20°) occurs in about a fourth of the country, continuing for more than 100 days in an area extending from northeastern Montana almost to Lake Superior, and for more than 50 days in most of Wisconsin, South Dakota, and Wyoming.

Map 10 affords a sort of summary of the seasonal contrasts in the United States. The Deep South, with daily normals above 50°,

has no winter or cool spring-fall. It has summer (means above 68°) and hot summer (means above 75°). Most of the upper South lacks winter (means below 32°). A broad central zone has all seasonal types except cold winter. Much of the North lacks hot summer, and a small part of it lacks summer. Most of the Pacific Coast lacks both summer and winter. Various high western mountain ranges also lack summer, while some valleys have some hot summer.

The causes of the conspicuous seasonal contrasts in the United States are chiefly, of course, the latitudinal width of the country, its variation in elevation, and the effects of the ocean, the Great Lakes, and lesser surface features such as smaller lakes, slope, soil types, and vegetation. Significant also are the effects of precipitation. The regions which receive much snowfall warm up more slowly than the regions otherwise comparable which have little snow or winter rain.

The much greater effect of the Pacific Ocean than the Atlantic shown by these maps reflects the fact that the winds much more often blow from the west than from the east. The Great Lakes have a conspicuous effect especially evident in those maps showing exceptional warmth and cold. The Appalachian Mountains cause irregularities in the lines of all of the maps. The western high mountains have even greater effects although not shown by these maps. This is largely because the Weather Bureau records from the western mountain regions used in the construction of these maps come almost exclusively from cities in the lowlands, which have quite a different seasonal climate than that possessed by the near-by mountains, some of which are snow-capped.

Those readers who desire more details on the normal duration of various temperatures may consult my article in the *Annals of the Association of American Geographers* for June, 1943. Further explanation of the causes of the differences shown by the maps in the present article is presented in "Some Influences upon American Climate of the Ocean, Gulf, Great Lakes, Latitude and Mountains" in the *Bulletin of the American Meteorological Society* for March and May, 1943. "Novel American Climatic Maps and Their Implications," in the *Monthly Weather Review* of the U. S. Weather Bureau for June, 1943, will also interest some readers of the present article.

UNIFORMITARIANISM

Earth's forces fill the mind with awe:
Volcanic burst and earthquake shock,
The glaciers grinding tons of ice,
The hurricane and river's flood,
Mountain bared by avalanche,
And every great catastrophe.

Yet in the end far mightier
Are raindrop, snow, and rivulet,
With alternating sun and frost—
Faint forces, multiplied by Time.

That mountains only slowly rise,
And wear away to level plain
With only causes commonplace
As those that lie before our eyes,
This simple doctrine, understood,
Opens a vista to eternal time.

—KARL P. SCHMIDT

THE PASSING OF THE SALMON

By JOEL W. HEDGPETH

I will say from my personal experience that not only is every contrivance employed that human ingenuity can devise to destroy the salmon of our west coast rivers, but more surely destructive, more fatal than all is the slow but inexorable march of these destroying agencies of human progress, before which the salmon must surely disappear as did the buffalo of the plains and the Indian of California. The helpless salmon's life is gripped between these two forces—the murderous greed of the fisherman and the white man's advancing civilization—and what hope is there for the salmon in the end?—LIVINGSTON STONE. Address to the American Fisheries Society, 1892.

SEVENTY years ago the chinook salmon of California was an important natural resource, as famous throughout the world as the gold, the redwood trees, and the city of San Francisco. With a prodigal disregard for the future, hundreds of thousands of pounds of salmon were taken from the rivers and canned for shipment to all parts of the world. The present-day salmon fisheries of the Columbia River and Alaska were nonexistent in the seventies of the last century—then the entire industry was restricted to San Francisco Bay and the lower Sacramento River. Any other than "California Salmon" was unheard of in those days. But that fishery did not last long. In less than twenty years it reached its peak and began to decline as quickly as it had risen. The canneries moved on to the Columbia, to Seattle and Alaska, and the words Alaska and Columbia River on the labels of the new cans became so familiar that most Californians forgot about their own salmon.

The canneries alone were not responsible for the decline of the salmon. It is possible that the intensive fishery between 1864 and 1882 had less effect on the salmon runs than the hydraulic mining which damaged hundreds of miles of rivers during those same years. Later, when the salmon were no longer considered an important resource in California, dams without fish ladders barred them from many spawning areas or held the water back from the river beds below, and unscreened irrigation ditches carried young salmon out in the fields by the millions to die. Yet all this was not enough to destroy the salmon completely. For years they have been coming back, trying to repopulate what is left of their rivers. But within the last few years man has devised new dams and water projects which will cut off much of the remaining spawning mileage from the salmon.

The year 1872 is a significant one in the history of the Sacramento salmon. In that year the newly established United States Fish Commision received an appropriation of $15,000 to be spent in the "propagation of food fishes." At a meeting held by Commissioner Spencer Fullerton Baird and attended by various New England fish commissioners and members of the American Fish Culturists Association, Livingston Stone, a retired minister who had recently taken up trout culture, suggested the importation of California salmon to replace the vanishing salmon of the New England streams. It seemed a good idea at the time, for it was not known then that the Pacific and Atlantic salmon are entirely different fish, with radically different life cycles.

In the late summer of 1872 Livingston Stone and two young assistants found their way to the McCloud River (Fig. 1), nearing the end of their quest for spawning grounds of the chinook salmon. As they picked their way between the rocks and trees along the river bank they looked into the water for signs of salmon. Many strange and rough characters roamed the hills of northern California those days—miners, hunters, surveyors, and less respectable individuals, but these three New England gentlemen in search of a site for a fish hatchery were a new sort. Stone, the retired Unitarian clergyman who sought outdoor work for the benefit of his health, was a stocky man, conspicuously shorter than his two companions. His round head was framed by a pair of elegant brown dundrearies which partially concealed his large ears. One of his companions was a massive fellow whose solid chin was softened

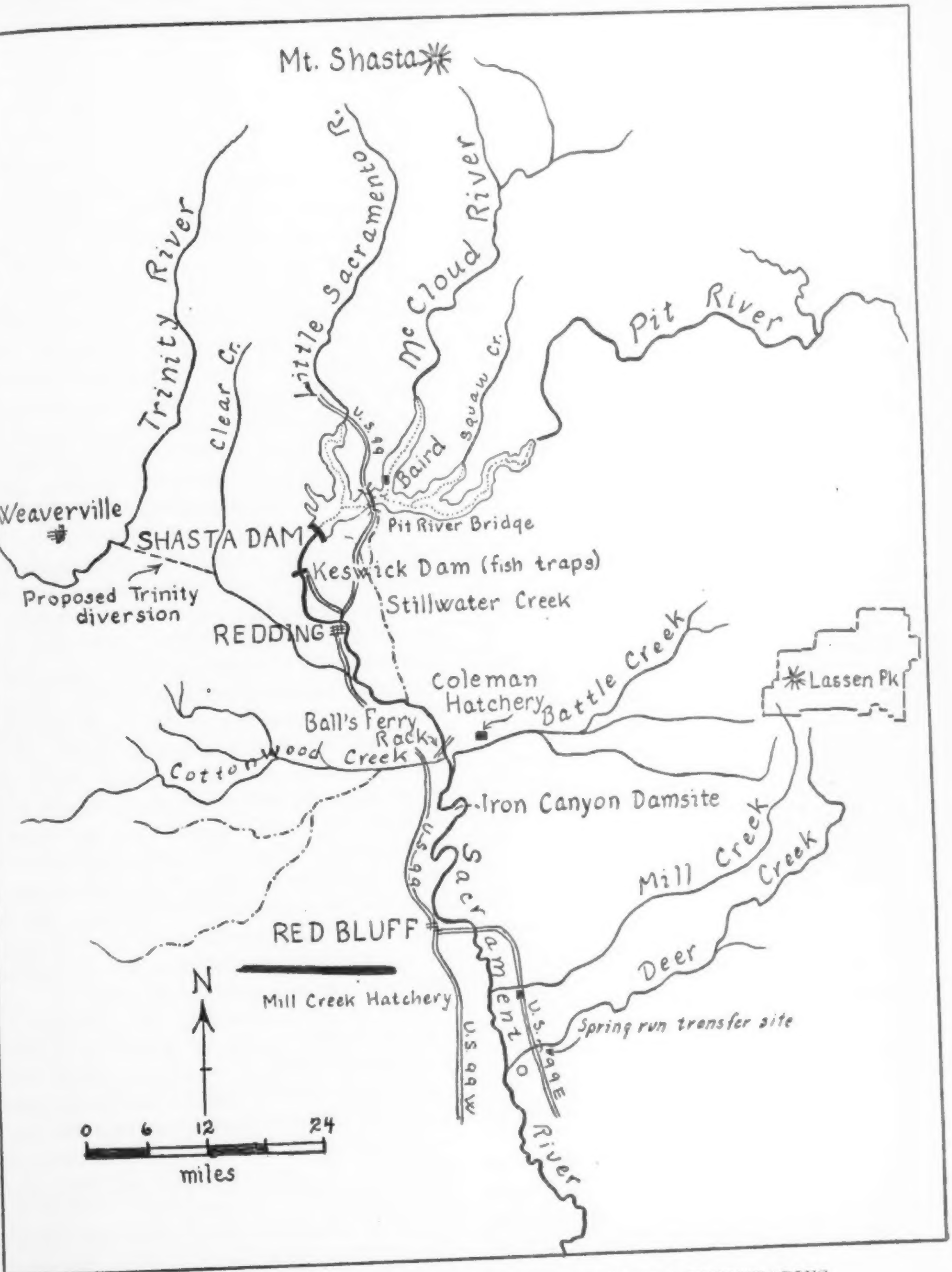


FIG. 1. THE UPPER SACRAMENTO RIVER AND ITS TRIBUTARIES

by a fringe of beard. The other was slighter, and beardless.

They did not have far to walk after leaving the ferry across Pit River just below the fork where the McCloud comes in, and they must have been unprepared for the scene ahead of them. Two miles upstream the McCloud turns toward the foot of a high

limestone crag, and then makes another turn to the left along the front of the crag. From the first turn the three men could see the gray rock towering above the dense forest, the smooth water at the farther bend, and the white churning of the water over the riffle at the nearer bend. To their left was a sandy beach and a low hill on which were clustered the brush huts of an Indian village. The Indians were fishing, wading out on the riffle with long double-pronged spears. On the other side of the river the forest grew almost to the water's edge. The retired parson named the crag Mount Persephone, but on the maps it now bears the prosaic name of Horse Mountain. The hatchery he built on the bank of the river within the morning shadow of the crag he named Baird in honor of the first Commissioner of Fisheries. Soon the new Shasta Dam will cover it under nearly three hundred feet of water.

The three men lost no time in getting down to work after arriving on this scene. They had hoped to hire the Indians to help them, but the Indians could speak no English. Working unaided in the hottest part of the summer, the fish culturists built a house, a flume for their water supply, and a series of hatchery troughs. The nearest sawmill was at the railroad terminus of Red Bluff, fifty miles to the south, and their lumber had to be hauled by wagon over the rough mountain roads. In spite of these difficulties the job was finished in two weeks, and on September 15 the first salmon were taken from the river. The hatchery became a famous place in northern California, as much for its cultured atmosphere—there were no oaths or card playing, and its superintendent became the acknowledged chess champion of the State—as for the queer things being done with salmon eggs.

Fish culture has not advanced very far beyond the practice of seventy years ago. Then a female was "stripped" of her eggs by squeezing her somewhat after the fashion of milking a cow. Today she is hit on the head with a club and the eggs cut out of her body, which is less wasteful of the eggs. After the eggs have been removed, a ripe male is forced to ejaculate milt over them. The fertilized eggs are then placed in baskets in long troughs of running water. For the first week or ten days they are picked over for dead eggs. After ten days the eggs become "tender" and cannot be handled. Even jarring the tray at this stage may kill all the eggs. Then, about fifteen or twenty days after fertilization, the eye of the embryo appears as a small black spot on the egg. In this eyed stage the embryo is very tough, and the eggs can be packed in trays with moss, burlap, or ice, and shipped to the far corners of the earth. They will hatch in six to nine weeks, depending on the temperature of the water in which they are placed.

The only important change in the above procedure has been the development of a drip incubator, in which the eggs are placed in shallow trays and water is percolated over them to cool them by evaporation. This method is not widely used, however.

The artificial propagation of salmon was so simple and obviously successful—after all, the fish were hatched—that it was assumed at the beginning that it was a notable improvement on the wasteful ways of nature. It is hard, in these sophisticated days, to realize the fascinated delight the early hatchery men took in their business of raising fish, how they watched over the eggs in the long troughs of cold water, picking them over with feathers like fussy hens, and the pride with which they watched the newly hatched alevins. They did not suspect that the natural hardihood and vitality of the eggs had as much to do with the success of their hatcheries as their human intervention in rescuing the eggs from the perils of the river.

That nature's methods of propagating salmon might not be as wasteful as they seem never occurred to them. Given half a chance, the salmon needs no assistance from man. It cannot, however, survive the total demolition of the rivers which is the inevitable result of power, mining, and irrigation developments.

During those early days of salmon culture in California no serious attempt was made to determine the efficiency of the natural spawning process. "In a state of nature, only two eggs in a thousand hatch," is the pontifical statement in one official bulletin. Livingston Stone dug into a nest and estimated that only "eight per cent" of the eggs

were fertilized. Although we still have much to learn about the life of the salmon, I suspect that natural spawning is at least as efficient as the hatchery method. Actual losses of eggs in hatcheries seem to range from five to forty per cent, with the emphasis in published records on the lesser figure. Nothing has been said of the possibility that hatchery reared fry may not be as healthy as naturally spawned fish. Certainly the practice of dumping large numbers of young salmon into a river was more hazardous to the fish than their natural method of emerging from the gravel, aside from any acquired differences in their constitution. In recent hatchery practice this danger to the young fish has been overcome somewhat by permitting them to escape from rearing ponds in a "natural" manner.

Livingston Stone and his contemporaries had no misgivings of this sort about the efficacy of fish hatcheries. While it should not be forgotten that the life cycle of the chinook salmon was not completely understood at the time, their assumption that the increasing fish catch was a demonstration of the value of the hatchery was a *post hoc* of the first magnitude. They did not consider that greater fishing effort can increase the catch in a declining fish population.

In the beginning the hatchery on the McCloud River was simply an egg-gathering station. During the first season 50,000 eggs were taken, of which 30,000 survived to the eyed stage. These were packed in sphagnum moss and shipped east. In March of the following year, 1873, a few hundred fingerlings were released in the Susquehanna River. Thus began the unsuccessful attempt to transplant the Pacific salmon to the Atlantic, which was not abandoned until ten or fifteen years ago.

We have learned a few things about the life of the chinook salmon since that day Livingston Stone and his two young assistants founded Baird hatchery. At that time no one knew when and where the salmon spawned, how often during its lifetime it spawned, or what happened to it after spawning. Although we are still trying to learn more about the wanderings of the salmon in the ocean, we have cleared up some of the points which mystified those pioneer fishculturists. Unfortunately we must still agree with David Starr Jordan, who wrote in 1896 that "writers of all degrees of incompetence, and writers with scanty material or with no material at all, have done their worst to confuse our knowledge of these salmon." Popular articles and newsreel shorts have perpetrated gross errors and even such an excellent book as Roderick Haig-Brown's *Return to the River* leaves important points open to misinterpretation by the lay reader.

There are five species of salmon of the genus *Oncorhynchus* (hooked nose) in the north Pacific Ocean. Two of these spawn in California rivers, but only one is found in the streams of the Central Valley. This is the chinook, quinnat, spring, or king salmon, referred to by ichthyologists under the formidable name of *Oncorhynchus tschawytscha*. The rainbow trout, a close relative of the Atlantic salmon, is also found in this drainage. The rainbow, a member of the true genus *Salmo* ("true" in the sense of being the first and best known genus of salmons), has races which leave the rivers and return as "steelhead" after a year or two of ocean life. The rainbow, or steelhead, unlike the Oncorhynchus salmon, can spawn several times.

The technical term applied to the salmon's habit of spawning in fresh water is anadromous. Some fish, notably the eels, are catadromous. They leave the rivers to spawn in mid-ocean. Whether the salmon is an ocean fish which spawns in fresh water or a river fish that has learned to go to the ocean for food and has not yet adapted itself to spawning in the ocean is apt to be an unprofitable argument, like the affair of the hen and the egg. The important thing to remember is that by spawning in fresh water, far from most of the hazards of life in the open sea, the salmon's relatively small number of eggs are given a much better chance for survival than if they had been released in the ocean to sink to the bottom in the presence of a horde of hungry gourmets. It is true that in a heavy run the reproduction may be less than when the run is moderate, because the salmon will dig up each other's nests. This frequently happens in Alaska, but the fact remains that natural reproduction did very

well until civilized man came upon the scene. It is strange that this did not occur to anyone in those days when it was still the fashion to inquire into the divine purposes of natural phenomena. Instead it was assumed that nature (and presumably, God) did *not* know best. No one thought of the life cycle of the salmon as an integrated phenomenon, in which the procedure of burying eggs in river gravel occupies much the same place in the salmon's life as the gray shark's method of hatching the eggs within its body, which insures maximum reproduction in spite of its limited fecundity.

The average life span of the chinook salmon is four years, but individual salmon may be six or seven years old before leaving the ocean, and a large percentage of some runs is composed of grilse. These are precocious fish of one, two, or three years stay in the ocean. Most grilse are males, but females are not uncommon.

Once it leaves the ocean and begins its migration up the river, the chinook salmon does not eat. It derives the energy for its difficult journey from the oil and fat stored up in its body during those years in the sea. The upstream migration is not always the continuous battle against powerful currents and waterfalls of popular fancy. In every stream there are eddies and backwaters, and the salmon makes use of these. Even when fighting rapids and climbing cataracts the salmon seeks out the places where the water can boost it against the main current of the stream. When at last it comes to a dam or sheer waterfall, it noses along the front of the falling water, seeking the center of the current. Then the salmon leaps, making a startling jump which is sometimes six feet clear of the surface of the pool. Such a leap may carry the fish cleanly over the crest, or it may send it into the solid green water at the brim. In either event, the salmon is over, for once it gets its broad tail into solid water it can go ahead. If the fall is more than a sheer six feet or the cascades are too long, even the largest salmon cannot pass and must fall back to spawn below the barrier, or fight the water until it dies, without fulfilling the mission of its life.

In the Sacramento River (Fig. 1) there are two principal runs: the spring run, which enters the river in March and April and passes Redding, just below the site of Shasta Dam, in May and June. One tagged fish made this journey of about 285 miles in 39 days; its average daily progress upstream was 7.3 miles. As the salmon of the spring run do not spawn until September and October, they must rest in cool deep parts of the river until they are sexually mature. The fall run leaves the ocean during the summer months and spawns in November and December. There also seems to be a small winter run which reaches the spawning beds in December and January.

When ready to spawn, the female salmon seeks out a riffle area at the lower end of a pool. Here, in gravel of medium size, from that of golf balls to apples, the fish digs a nest, or, as the English call it, a redd. The salmon accomplishes this by turning on her side and flapping her tail against the gravel. This creates a current on the bottom of the river which lifts the gravel. The current of the stream carries the gravel downstream until a fan-shaped pile of stones accumulates behind the pit. The hole thus dug is from six to eighteen inches deep. It usually reaches down to the finer gravel and sand beneath the coarse gravel of the river bed. Some observers believe that the salmon uses her tail and nose to dig into the gravel with a spading action, but I have not seen this myself. Only the female seems to dig the nest. The male hangs around, usually fighting off possible rivals.

After the nest is dug, spawning takes place. As the female discharges her eggs, the male swims alongside and releases his milt. Only a few hundred eggs are released at a time and are covered up after fertilization by the digging of another pocket upstream. In these pockets there is almost no current, and the eggs are seldom lost from the pockets in which they have been spawned while being buried. When all the eggs are spent, usually about 7,000 in the case of the salmon of the Sacramento (there may be as many as 10,000 or 12,000), the female, her tail and fins worn threadbare, guards her nest until the life ebbs out of her and her corpse drifts downstream. The male also dies.

When the eggs hatch, perhaps in sixty

days, the alevins, with their yolk sacs still clinging to their bellies, begin to wriggle out of the gravel in which they were born. During the first few weeks of their life, the young salmon live along the edges of the river, feeding on the insects that are abundant in the gravel-bottomed parts of the stream. Then the young fish begin to drift downstream toward the ocean. Some of them, having wintered over in the river, are about three inches long, others are barely large enough to shift for themselves. At this stage, when the fish are distinguished by marks like thumb prints along their sides, the young salmon are known as parr. They look very much like young trout. As they near the ocean, the parr begin to lose their markings and become young salmon.

Once in the ocean they grow rapidly, feeding on the nutritious crustaceans of the oceanic plankton. They wander in large schools up and down the coast, often hundreds of miles from the mouths of the rivers in which they were born. As the salmon grow, their scales also grow, and their growth is marked on the scales in rings like the yearly rings of the growing tree. By examining these scales, the approximate age of the fish can be estimated. Some have claimed that much more is written upon fish scales for him that knows the signs, but the salmon of the Sacramento River do not have scales as plainly marked as those of other regions.

It is usually taken for granted that the salmon returns to the stream in which it was born. It has not been proven to everyone's satisfaction, however, that all salmon return to the same stream in which they were born, or even that most of them do. Some outspoken dissenters to the theory that salmon find their way back to their native stream by instinct or "homing tendency" insist that the salmon respond to the carbon dioxide gradient of the water and that they might be enticed into suitable streams by tampering with the chemical balance of the water. Others suggest that the temperature of the water influences their selection of a stream. While neither of these schools of objectors has explained the embarrassing reluctance of all the salmon in a run to ascend the first stream that attracts the vanguard, something besides a mysterious subjective instinct or phenomenal memory, it seems apparent to anyone who has seen salmon runs, influences their selection of a stream.

There are, for example, the runs of two tributaries to the Sacramento: Mill and Battle Creeks (Fig. 1). Both of these streams have had hatcheries near their mouths for nearly fifty years, and for many years most of the salmon to enter these streams were intercepted and artificially spawned. The eggs were moved to Baird or to the state hatchery near the headwaters of the Sacramento River for hatching. Yet every year salmon continued to run into the two small streams in spite of this heavy drain on their spawning populations. Later, when the young fry were released into the same streams from which their parents had been taken, there was no significant change in the runs. In other words, there was no effect, favorable or adverse, on the salmon runs of Mill and Battle Creeks, as a result of human intervention. There are several possible explanations for this behavior. According to the home stream and natural spawning enthusiasts, enough spawning salmon escaped the fish-culturist's tender mercies to maintain a natural run. The numbers of salmon involved make this hard to believe. My own opinion is that the runs in these small streams are diversions from the main river run, attracted into the side streams by some quality of the water. It is significant that the salmon usually do not start to run in these streams until the fall rains have begun. No biologist is willing to admit that the homing instinct is hereditary, or acquired while the fish is still an egg, and such explanations are dismissed in passing, although there are stranger examples of instincts in the world of nature. The results of the only marking experiment conducted with Sacramento River fish would seem to support the explanation of diversion from a main run.

In this experiment, 15,400 fry hatched at Mt. Shasta from eggs gathered at Mill Creek were marked by clipping off two of their fins. None of these fish was recovered in the upper Sacramento River—which does not mean that none of the fish returned there, of course —but six adult salmon with mutilated fins were taken in Mill Creek and fifteen were caught at Battle Creek hatchery. If these

were the same fish, the experiment demonstrated that at least 21 of the 15,400 salmon returned to the same drainage basin in which they were released, and, further, that they apparently strayed from the main river, which was their adopted stream.

From time to time similar experiments have been made in other streams to test the home stream theory, usually by this method of marking young salmon and waiting for the return of the adult fish several years later. In none of these experiments has the number of returned fish been large enough to prove that most salmon return to their native stream. Such unregenerate critics as Dr. Henry Baldwin Ward steadfastly refuse to be convinced, and their position is best stated in Dr. Ward's words:

> No assumed mystical impulse makes them go back to a specific place because of their relation to that place at the start of their existence. They do, perhaps usually, return to the place because like their ancestors they react in a specific way to the stimuli they encounter on the journey. But they do this only so long as the conditions they meet on the journey remain unchanged. To characterize the situation as due to a parent stream theory is to adopt an empyrical [sic] conclusion with all the errors and limitations of empyrical findings. It is to abandon the search for a scientific basis and to lose the greater power over changing conditions which knowledge of controlling influences will give.

The genesis of the home stream theory has never been traced; it seems to have arisen as a spontaneous induction by analogy from similar phenomena in birds and bees. The strongest evidence in favor of a homing instinct is not experimental but anatomical or physiological. The average number of eggs in the Columbia and Sacramento river fish is different, and there also appear to be differences in such things as the number of gill rakers and pyloric caeca. While this indicates the existence of separate races in different river basins, it does not prove that salmon return to the identical tributaries in which they were spawned. If we do accept some sort of homing instinct as governing the salmon's journey for hundreds of miles in the open ocean from the mouth of the river in which it was born and back to the river, we have not settled the matter. Giving a phenomenon a name is no explanation. This discussion would be academic were it not for the various attempts to repair the damage being done to salmon streams by hydroelectric and irrigation projects by "training" salmon to spawn in new streams. These experiments place more trust in the homing instinct than is justified by the available evidence.

The most spectacular example of this experimentation with the lives of the salmon is the salvage program for the salmon of the Columbia River below the Grand Coulee Dam. The salmon are being intercepted at Rock Island Dam, 120 miles downstream from Grand Coulee. They are carried in special trucks to other streams which enter the Columbia between the two dams. Some of the fish are released to spawn in the rivers; others are handled at the Leavenworth hatchery and their fry released in the rivers. Since there is no way of determining which of these fish would have entered these streams of their own accord and which would have passed on to the upper Columbia, all the salmon that reach Rock Island Dam are taken. It is hoped that the salmon spawned or released in these rivers will return to the same streams and that it will not be necessary to intercept them at Rock Island Dam after the first complete cycle. If the fish do not justify this faith in their homing instinct it will be necessary to haul them from Rock Island Dam perpetually. The next year or two will answer the question, insofar as this part of the Columbia drainage is concerned. The first run, which returned last fall, is said to have behaved nicely. What is to happen on the Sacramento River is a different story—California is without such large streams as the Okanogon, Wenatchee, and Entiat Rivers in which to transfer its thousands of dispossessed salmon.

Although it will not be completed for several years, the Central Valley Project of California has reached the stage at which some of its major structures have become serious menaces to the existence of the salmon. As originally planned, this Federal project was to consist of two dams and a series of irrigation canals and pumping systems. The water stored at Shasta Dam on the upper Sacramento River will stabilize the flow of the river and generate power. A large part of this flow, according to the

original plan, was to have been taken up by pumps and shunted across the inverted delta area between the confluence of the Sacramento and San Joaquin Rivers. Then it was to be picked up by another pumping system and forced down to the middle San Joaquin Valley, to replenish the underground water of that region. Water was to be supplied to the upper San Joaquin Valley from Friant Reservoir on the San Joaquin River.

Of these three primary elements, Friant Dam is complete and Shasta almost so, but the Delta Cross Channel still remains in the blueprint stage. Instead of carrying out this last feature, it is now planned to construct two dams on the American River, about midway between Shasta and Friant Dams.

Although the Central Valley Project was commenced in 1936, with considerable fanfare and some rather gaudy publicity about "moving the rain," it was not until the summer of 1938 that any investigation of its possible effects on the salmon of the Central Valley drainage was begun. The first season's work of the investigation revealed an unexpectedly large run of salmon passing the site of Shasta Dam, and as later counts indicated, the run was on the increase. Apparently the Central Valley Project could not have been started at a more inopportune time as far as the salmon were concerned. While circumstances prevented an entirely complete count, the run seemed to be about 40,000 fish, all chinook salmon. This is about twice the number of chinook salmon being handled below Grand Coulee on the Columbia.

Every remaining stream in northern California was investigated in the hope of finding a place for these fish, but there is nothing left but a few streams hardly large enough to accommodate their own depleted runs. A fish ladder over such a dam as Shasta, which will be 560 feet high, is out of the question, nor would it be practical to trap all the salmon and transport them above the dam, because the ocean bound fry would have to be screened from the penstocks and river outlets by screen of not more than quarter-inch mesh, and they could not survive the fall over the spillway when the reservoir is full.

At first it seemed that it might be possible to rehabilitate one of the intermittent streams near Shasta Dam with water from above the reservoir, but this plan proved to be economically and biologically unsound, and was abandoned. At the outset it was realized that there would be more salmon than any program of stream rehabilitation or transfer could handle, and that it would be necessary to construct a hatchery if a serious attempt to save the salmon was to be made. There were very few suitable hatchery sites in the Valley, and almost no place to hold a large number of spring run salmon, which have to be kept in cold water (60° F. or less) during the hottest part of the summer in order to survive until ripe for spawning. Only Battle Creek (Fig. 1), of the streams within fifty miles of Shasta Dam, might be used for this purpose. The history of the existing Battle Creek hatchery offered little encouragement for further hatchery development, but as the best had to be made of a bad bargain, a new and larger hatchery has been built. As many salmon as possible are to be carried by trucks to Deer Creek, which enters the Sacramento about sixty miles below Shasta Dam, but the number of fish which this stream can hold is very small.

For most of the run, there was nothing left but the river itself. Accordingly, a series of racks has been installed, and the salmon are being held in the river between Keswick Afterbay Dam near Redding and the mouth of Battle Creek. Although it will require several years to determine experimentally whether the salmon can be trained to spawn between these racks instead of in the headwaters where their ancestors did, a large number of salmon have spawned in the areas, and those concerned in the administration of the experiment have been cautiously optimistic in their public declarations. Unfortunately, there are indications that this experiment may not be given a chance to prove itself. Within the last few months the U. S. Engineers have announced plans to dam the Sacramento at Table Mountain near Red Bluff as a flood control measure. This dam would undoubtedly be too high for fish ladders, and in spite of the artful references to a "low level" structure, it will back up water far enough to flood out the new hatchery. Official recognition of this conflict in agency plans has not been realistic, and the Engi-

neers have given no intention of being willing to defer their project for several years until the Bureau of Reclamation salvage project is given a chance. Until this issue is settled, the salvage project can only be considered an expensive laboratory experiment. But the Bureau of Reclamation itself appears to be more concerned about the possible conflict in power production than the danger to its salmon project. When storage of water was begun at Shasta Dam in the winter of 1943–44, public action was necessary to prevent the Bureau from cutting down the river flow to such an extent that large areas of spawning beds would have been left dry, in the very parts of the river it had spent half a million dollars to develop for the benefit of the salmon.

The salmon population of the lower Central Valley in the tributaries of the San Joaquin River is even larger than the run in the upper Sacramento. During the year 1940, for example, more than 170,000 salmon were counted into such rivers as the Tuolumne, Merced, and upper San Joaquin. The salmon's lot may be happier in these streams than in the Sacramento. There are fine gravel areas in these rivers below the dams that have been built or are being planned. The original plan of the Central Valley Project to dry up the San Joaquin, without any concern for the appearance of the river or the needs of the fish, will have to be altered to allow living room for these fish. Recent observations of the behavior of salmon blocked by Friant Dam indicate that the spring run fish, at least, will fall back downstream to spawn, and the recognition that fish may have some water rights may undo some of the damage that has been done in these streams over the years.

Unfortunately, there seems to be no end of engineering plans in sight. It might be possible to arrive at some adjustment between salmon and engineering if the latter were stabilized. Whatever the reasons behind the apparent abandonment of the Delta Cross Channel, the engineers in charge of the project assure us that this element of the plan has not been abandoned but only deferred. If constructed, the Delta Cross Channel and its pumping plants would present formidable difficulties to any salmon salvage or conservation program because of its huge pumps and diversion barriers. Nor is this all. There is a plan ultimately to cut off the entire river system by a salt water barrier at the upper end of San Francisco Bay. This barrier, if constructed, would cut off all other fish, such as striped bass and sturgeon, which pass from salt to fresh water, as well as the salmon. As for the Columbia, the construction of dams has barely started. A dozen more are to be built as soon as the war is over.

In spite of the fact that most of these projects are already in the blueprint stage, we are still assured that every effort will be made to save the salmon. Indeed, the official press release from the Bureau of Reclamation, on the occasion of the initial generation of power at Shasta Dam, states that release of water from the dam will "protect the salmon and other fish and wildlife interests." But there can be such a thing as too many dams, and it would be more honest if the agencies concerned were to admit frankly that the passing of the salmon is an inevitable result of their projects, instead of issuing such misleading press releases. If this possibility had been admitted before the start of the projects, it is possible that they would not have been so enthusiastically received, for no matter how insignificant the intrinsic value of a salmon run may appear to be when set against the dazzling prospectus of millions of dollars worth of dams, the fact remains that a salmon run is, if properly respected, a perpetual natural resource.

It may already be too late, as far as the Sacramento, and perhaps the Columbia, is concerned, to recognize that a river has certain natural functions which should be respected above its use as sites for public works projects, but there are other rivers, especially in Alaska, where the water rights of fish should be respected even more than the artificial rights which man recognizes in his law courts. For, as Harold Child Bryant wrote in 1929:

> There are certain natural resources which are far more valuable than any handiwork of man. When people are hoodwinked into believing that the brains of man can build artificial structures more useful to civilization than raw materials represented by natural resources, danger is ahead. Works of man may be built and destroyed at will, but there is yet to be found a man who can create a natural resource, such as is represented in fish life.

THE PROBLEM OF ORGANIC FORM*

IV. CHEMICAL EQUILIBRIUM AND ORGANIC INTEGRATION

By S. J. HOLMES

Life is the expression of a dynamic equilibrium which obtains in a polyphasic system.—F. G. HOPKINS.

IN our endeavors to penetrate into the mysteries of life we are often led to fix our attention on those characteristics of nonliving bodies which find parallels in the activities of living organisms. The hope of throwing some light on fundamental life phenomena has afforded a potent spur to researches on the form, molecular arrangement, and regeneration of crystals; the chemical nature and synthetic and destructive action of enzymes; the properties of semipermeable membranes; the behavior and structural make-up of colloids, and many other phenomena of biophysics and biochemistry. These researches are being carried on by an army of technically trained investigators who are turning out an imposing and rapidly swelling flood of literature, most of which would be unintelligible to the typical biologist of the Victorian era. Turn over the pages of *Biodynamica, Growth,* the *Journal of General Physiology, Bios,* or *Protoplasma* and one encounters a large proportion of papers which cannot be adequately understood without more knowledge of mathematics, physics, or chemistry than is possessed by most biologists of the traditional sort. The task ahead of this modern army is colossal. Its soldiers are inching along over a wide front, sometimes by-passing and closing in on positions which have long proved impregnable to a frontal attack. Not improbably we shall see the fall of some old strongholds in the not distant future.

The efforts of the biological speculator in contributing to the successful assault on fundamental positions, while often of doubtful value and sometimes even meriting the reproach of being only an obstacle to progress, are, of course, essential for advance, and they frequently perform a valuable service even if misguided. If one looks back over the history of theories of development and regeneration, it will be seen that a number of speculations that have proved to be wrong have led to experimental researches which have yielded valuable new insights. In the development of theories of morphogenesis there is a tendency to get away from artificial constructions like the physiological units of Spencer, the plastidules of Haeckel, and the gemmaires of Haacke, and to interpret the phenomena in terms of known processes, whether physical, chemical, or physiological. But the basic defects of so many of the modern, as well as the older, speculations on morphogenesis is that they are not theories of balancing. The field theories and the doctrine of gradients, and those based on so-called "crystal analogies," whatever elements of truth they contain, all suffer from their inability to give a plausible account of the coadaptations which play an indispensable role in formative processes.

In the view which I have developed in the preceding papers, morphogenesis is largely a result of physiological balancing. The term balancing implies a tendency to settle into a state either of immobility or of action which runs along in a fairly even course. Organisms possess many mechanisms by which their functions are checked when in excess and speeded up when they lag below a certain norm. In this way a balance is maintained which tends to keep things running *in statu quo*. If we seek an analogue of this kind of behavior in the nonliving world, we may find it in the tendency to equilibrium exhibited in ordinary chemical reactions. When one adds acetic acid to alcohol, to use a well-worn illustration, there is obtained a certain amount of ethyl acetate and water. The reaction stops short of transforming all of the alcohol, leaving a definite proportion of alcohol, acetic acid, ethyl acetate, and water, which depends upon the relative masses of the ingredients employed and also upon temperature and other external factors. Should any one of the ingredients be removed, more of that substance would be

* Continued from p. 260 of the preceding issue.

produced until a new equilibrium is reached. Regeneration of the missing substance is, as a rule, direct and it comes to an end when a new balance occurs.

What is the relation of chemical balancing to the balancing which occurs in the physiological activities of the organism? And is it also possible to construe in terms of chemical equilibration the regulatory form changes that take place in development and regeneration?

That the functional and formative activities of living organisms regulate themselves in ways that are fundamentally akin to those involved in ordinary chemical transformations may be regarded by many as a grandiose generalization based on a slender and far-fetched analogy. Whatever be the merits or demerits of the idea, it may be worth while to explore its possibilities somewhat, and perhaps all the more so because it presents a viewpoint that has attracted little attention on the part of most writers on the problem of organic form.

Were one to state that all biological processes are physical and chemical in the last analysis, and that the principles of mass action and chemical equilibrium apply to them as much as in the inorganic world, many biologists would assent at once. But a bare formulation of this kind would not be very helpful unless one can make its application more clear in relation to specific problems. The role of chemical equilibration in the integration of bodily functions is dwelt upon extensively in the literature on physiology. I need not discuss the part played by mass action in the chemical changes occurring in respiration and in the maintenance of the normal pH of the blood. In many other ways functional balancing seems to be chemical balancing plus certain accessory responses on the biological level.

One may well imagine that chemical equilibrium may be a dominant factor in many cases of functional hypertrophy. In a possibly overambitious paper on "The Problem of Form Regulation," published in 1904, in which stress was laid on the possible connection between form regulation and chemical regulation, I ventured to suggest:

> **If the checking of the growth and functioning of an organ when its products reach a certain degree of concentration is due to the fact that a chemical equilibrium is reached which prevents more of those substances from forming, the self-regulation of functions which goes on in an organism may to a great extent be the outcome of the tendency toward chemical equilibria. . . . if a particular substance is gotten rid of with more than the usual readiness we should expect that substance to be produced in increased amount.**

This, in many cases at least, would probably lead to an increased development of the organ or part concerned. I would not assert that all cases of functional hypertrophy can be interpreted in so simple a manner, but the case may serve to illustrate a possible way in which a widespread mode of physiological, and hence of form, regulation may be brought into relation with the principles of chemical equilibration.

An important role in balancing activities is played by the inhibitory effect of an organ's own products. A yeast cell in a sugar solution continues to split up the sugar to form alcohol and carbon dioxide until the percentage of alcohol reaches a point at which it checks its own further production. This cessation is not due to a reduction of the food supply. It can be brought about at any time by the addition of alcohol to the medium. The precise steps by which alcohol results in checking the enzyme activity of the yeast cell we do not know, but it is not unreasonable to look upon the whole process as one of chemical equilibration. If we were to add some substance which would combine with the alcohol in a way that would render it innocuous, the yeast cell would doubtless respond by producing more alcohol. Suppose now that this substance were produced by some other organism occurring in the same solution. If not injurious to the yeast plant in other ways, the organism would tend to enhance the enzyme activities of the yeast cell and probably lead to its growth and multiplication. If the alcohol contributed as food or otherwise to the vital activities of the second organism, we would have a sort of symbiotic relationship which would tend after a time to settle automatically into some kind of a balanced state. Up to a certain point each organism would tend to evoke the functional hypertrophy of the other. We have assumed that similar relationships are widespread among the various parts of a

living organism and that they automatically lead to functional adjustments which play an important part in building the organism as well as in maintaining its life.

The general failure to accord adequate recognition to the role of chemical equilibration in formative processes is doubtless due in part to certain evident differences between chemical balancing and the processes of morphogenesis. Two outstanding differences are (1) the tendency of chemical equilibration to result in homogeneity throughout the mass, or a relatively small degree of diversity where a gas or a precipitate is formed, and (2) the tendency of chemical processes to settle down into a state of apparent rest in which, under constant conditions, energy changes between the mass and the environment do not occur; whereas in an organism they continue to increase in complexity and amount over a considerable part of the life cycle. The first of these topics has been discussed briefly in Part III, "The Problem of Divergent Differentiation," in which it was pointed out that increasing differentiation is made possible under the peculiar conditions in which chemical reactions take place in the colloidal structures of living substance. The conditions differ from those in a glass container because the organic container actively participates in the reactions that occur and is itself built up and torn down and remodeled by these processes. It is provided with many kinds of enzymes and enzyme precursors which are affected differently in different regions and which produce compounds which, instead of diffusing uniformly, are in part anchored *in situ* and build up new complex colloidal configurations. Enzyme action is often greatly accelerated through adsorption on the colloidal structures of protoplasm, as is shown, for instance, in the ingenious experiments of Warburg on respiration. The action of these enzymes, which goes on most rapidly when adsorbed on colloids, naturally varies with the structural character of a living substance and the extent of its exposed surfaces. The adsorption of various colloids on the surface of micelles produces variations in the ways in which the micelles join together to build up crystalline aggregates. These and other factors may affect the local variations in the formation of fibrils, colloidal networks, and other configurations arising in histogenic differentiation.

The basis for the structural complexity exhibited by higher organisms is in large part the possession of a varied assortment of genes which, by the constructive enzyme actions they inaugurate, give rise to different products, some of which diffuse out and serve as evocatory agents that arouse different kinds of genes in other areas. Under the conditions indicated, chemical equilibration, instead of leading to homogeneity, may actually give rise to regional diversity as a result of the evocatory effects of gene action. Genes can only exert enzyme activity when the proper substances are available. These may be furnished by the action of other genes. At different times genes which have hitherto served only by standing and waiting are aroused from their lethargy and begin to play an active part in the production of further changes. As more substances are produced, more genes are called into service until a degree of complexity is reached which is determined by the original gene complex and its cytoplasmic investment. These genes in their setting furnish the original cast with which the drama of development begins. They enter upon the stage at stated periods as the plot unfolds. At times, since the drama does not always run smoothly, they may appear to exercise considerable ingenuity in improvisation. But, as we have before contended, their behavior is really very stereotyped, and their seeming originality is provided for in advance by the playwright.

The dynamic equilibrium occurring in an organism is sometimes designated as a "pseudoequilibrium," and contrasted with that occurring in chemical reactions because it involves continuous imbalance and changes of energy. Life, it is said, is possible only because equilibrium is never attained. Something always happens to upset the balance. In this respect an organism is like a candle flame, with which it is often compared. The flame is in a state of dynamic equilibrium and maintains a constancy of form despite outer changes by which it is modified. Forces that make for static equilibrium are ever operating, and if the flame were enclosed in a container cutting it off from

everything else, it would quickly resolve itself into an inert mixture of gases. It is normally prevented from so doing by a continued intake of energy contained in the melted tallow or wax. This supply of energy converts it into a dynamic system ever striving toward a static condition. The final result of burning is a lot of compounds in which potential energy differences are leveled down. In an organism the situation is much the same. Among plants a rather exceptional procedure occurs in the ability to employ the light of the sun to build up energy-yielding carbohydrates. Plants are comparable to candle flames that make their own tallow by absorbing free energy from their environment. The plant, if it can be called a plant, that first accomplished the Promethean theft of fire from heaven and made its energy available took a step of incalculable importance in the evolution of life. An imposing monument should be erected in its honor.

After all, the distinction between static and dynamic equilibria need not disturb us. Fundamentally it is food, or sunlight which is used in the synthesis of food, that continually unsettles the organic balance and furnishes the energy for running the living machinery. A part of this energy is used in the endothermic reactions involved in forming complex organic compounds. Its disposal and direction in building is largely determined by genes, which we must be careful not to look upon as little deities but as centers of activity quite strictly under the control of the essentially democratic system.

Amid all the diversities that result from the process of development, the original cast of genes is retained and forms the basis of the power of reproduction and the restoration of lost parts. The material basis for all the chemicals required for morphogenesis resides in every part and constitutes the potency of working out new equilibrations.

Sometimes dedifferentiation forms an essential part of the remodeling of organic structures in preparation for new construction. An essential condition for reconstruction is afforded by the labile state of living matter, which is often in a transitional state between a sol and a gel. Regional differentiation is associated with different types of gelation, and it does not tend to become swamped out through chemical equilibration because of its semisolid consistency. Under altered chemical conditions many fixed compounds may undergo solution, and then equilibration would tend to undo the work of producing structural diversity, and the system would be brought back to a state in which it can make a new start. Changes of phase play a role of enormous importance in form regulation. Gelation and solution are the favorite procedures employed by the architect and remodeler of the living body. The formation of a more or less solid framework permits the organism to accumulate structural diversity and hence to run through with a sequence of changes. These semisolidifications give the diversities that arise through interaction the degree of permanence required in building and also the degree of modifiability required in regulatory adjustments.

In the early stages of development and in lower organisms the formative reactions are elicited mainly by contiguous parts. Experiments have supplied many instances of such influences, although efforts to determine the substances producing the evocatory effects have thus far yielded only a modest return. In a complex organism containing many specific chemical factories in different regions the part played by chemical products as formative agents is more conspicuous, as is illustrated by the functioning of the endocrine glands. Under such conditions chemical equilibration involves a system of exchanges in which the *milieu interne,* the great stabilizer, constitutes an essential medium. Organ A contributes its products to this medium and therefore affects organ B (to say nothing of others), which responds by changing the medium in ways that modify the functioning of A. Balancing comes to be a many-sided process involving all the chemical factories of the organism, and it is often brought about in very roundabout ways and may even enlist the services of gross physical changes.

Whatever relationships exist between chemical equilibration and physiological and morphogenic integration are greatly obscured by the complexities of the latter phenomena. These complexities have grown up

in large part through what may be termed a successive accumulation of intercalations. The primitive relationship between A and N, instead of being direct, comes to be mediated by other activities D, E, F, etc., which have their specific structures relating to their specific activities. The hunger of a yeast cell may be satisfied by increased absorption of food owing to a deficiency in its protoplasm. A similar lack in the protoplasm of a lion is compensated in a very indirect way involving search for food, efforts to overcome and devour prey, the operations of mastication, swallowing, digestion, and others which enlist the activities of nervous reflexes, the secretion of digestive glands, and the co-ordinating functions of several hormones. In a paper on "How Life Becomes Complex" I have pointed out that in the course of evolution the basic functions have become associated with secondary activities which are subservient to their performance and that these in turn became associated with other activities which conduce to their performance, so that function B, which is subservient to A, is followed by the development of C subservient to B, D to C, and so on until a long chain of diverse activities very different in kind and in their associated structures is finally formed. Thus, the spinning of an orb web by the spider is the last event in the evolution of a chain of superadded, accessory activities that conduce to the primitive function of assimilation. This accumulation of acts and structures accessory to others which are accessory to still others makes functional relations very involved and the processes of physiological integration correspondingly complicated. The equilibration of basic functions comes to involve the regulation of many other subsidiary activities by which they are carried out. The maintenance of a fairly constant pH in our blood, for instance, is accomplished by means of secondary procedures, such as the functioning of the kidneys, the reflex activities of the respiratory center set up by carbon dioxide in the blood, and other reactions enlisting the services of various organs of the body. Basically the process may be considered as one of direct chemical equilibration, as in one sense it continues to be, but it has come to enlist the aid of accessory activities to such an extent that one might almost view the whole of life as centering around it.

In a relatively simple organism, such as an unfertilized egg cell, one may reasonably look upon most of its regulatory powers as springing from the equilibrating action of physical and chemical processes. After the removal of a part, the cell would round up, and the altered proportions of the various stuffs in the cytoplasm would be brought back to a normal distribution through chemical equilibration. The cell has a physiology of its own, which involves the basic functions that are carried out in the adult by very elaborate mechanisms. When one tries to imagine how these two physiologies are connected by intermediate stages, as they must be, he becomes lost in a speculative maze. Each stage tends to regenerate its own lost parts and to regulate its own functional balance. But these adjustments result only in a restoration of a passing phase. We might conjecture that each stage tends to pass on to the next for essentially the same reason that it tends to restore itself. Each step made in meeting one condition may incidentally involve a further imbalance which, by awakening a hitherto dormant gene, may participate in effecting a new approximate balance. So life becomes a ceaseless striving for a peaceful heterogeneous equilibrium, the attainment of which would result only in death.

MAN'S MOST CREATIVE YEARS

QUALITY VERSUS QUANTITY OF OUTPUT

By HARVEY C. LEHMAN

In previously published studies[1] it has been found, for numerous kinds of creative endeavor, that a brief age interval exists during which men are most likely to be maximally efficient. Both prior to and subsequent to the optimal age level of greatest efficiency, men tend to do somewhat less than their very best work. The present study sets forth the relationship between quality of output and quantity of output.

How can we make a quantitative comparison of quality and quantity of scholarly and artistic work with respect to the ages of those who produced them? In a given field of endeavor we must take a good sample of the works that are regarded by authorities as outstanding, and we must know the name of the author of each work and his age when he produced it. These superior works we shall regard as representing "quality." Then for comparison we must take a larger sample of similar works (by the same or by different authors) which for one reason or another must be regarded as of lesser merit than those of the first sample. These more numerous, run-of-the-mine works we shall regard as representing "quantity." Having acquired such data, our problem is simply to make a fair comparison of rate of production of outstanding works and of less significant works at several age levels, or age classes, throughout the productive years of man's life. Such comparisons are always made by means of graphs. The simplest representation of the data would show the number of works produced at each age level in the form of a frequency distribution. But two such curves would not yield a fair comparison of our data for two reasons: first, our samples are not of the same size; second, the number of younger workers exceeds the number of older workers and consequently the output of the former group would be expected to exceed that of the latter. We need a method of comparison that will eliminate absolute numbers and put production on a percentage basis. Therefore, instead of plotting numbers of works against corresponding age levels, we shall plot the average annual production per individual in each chosen age level of 5, 7.5, or 10 years. Furthermore, we shall express the average annual production per person in each age level as a percentage of the highest production, which we shall call 100 per cent. Thus every curve in the graphs of this article has a peak at 100 per cent. In all graphs the solid line represents age distribution of rate of production of outstanding works; the broken (dot and dash) line, works of lesser merit; and in two graphs a dotted, or dash, line, works of still lesser value. In the manner described comparisons were made of quality versus quantity of output in eleven different fields of endeavor. The results are illustrated and discussed in the paragraphs that follow.

Geology. The solid line in Figure 1 presents the chronological ages at which 65 individuals, now deceased, made 99 notable contributions to the science of geology. The data employed were obtained from *A Source Book in Geology*[2] by Mather and Mason, who give extracts from contributions that they regard as the most important. This line reveals clearly and unmistakably that, in proportion to their number, men have made notable contributions in geology most frequently during their thirties.

What is found when an analogous age-curve is constructed for geological contributions of somewhat lesser average merit than those listed by Mather and Mason? The broken line of Figure 1 presents age data for 5,386 geological contributions[3] by 169 geologists, now deceased, the average number of contributions per individual contributor being 31.86. It seems obvious that these 5,386 contributions are of *lesser average merit* than are the 99 contributions listed by Mather and Mason. If this assumption be valid, the broken line may be said to reveal quantity of geological output at successive age levels. It attains its apogee at ages 70

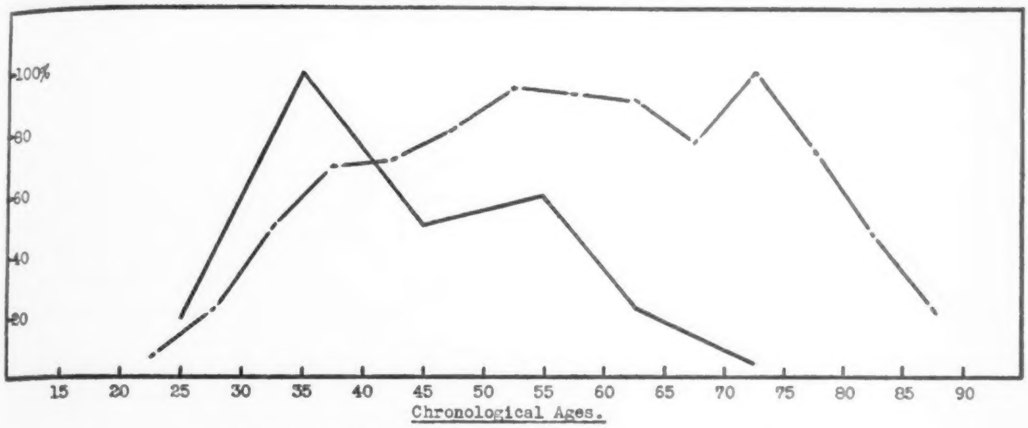


FIG. 1. AGE VERSUS PRODUCTION IN GEOLOGY
Solid line, 99 SUPERIOR CONTRIBUTIONS BY 65 GEOLOGISTS WHO WERE BORN BETWEEN 1801 AND 1857. *Broken line,* 5,386 CONTRIBUTIONS OF LESSER MERIT BY 169 GEOLOGISTS BORN BETWEEN 1800 AND 1833.

to 74 and sustains itself rather well over a wide age range. In contrast, the solid line rises more rapidly to a peak at 30–39, and it also falls off at a more rapid rate.

A curve that pictures a large number of works per contributor tends to remain high at most age levels because it requires many years of effort for a group of men to produce an average of 31.86 geological works. But why does the peak of production for the more carefully selected contributions occur so much earlier than does the peak for quantity of output?

Psychology. In Figure 2 the solid line presents the ages at which 50 psychologists, now deceased, made 85 important contributions to their science, the average being 1.70 contributions per contributor.[4] The broken line sets forth similar information regarding 4,687 contributions by 339 contemporary psychologists.[5] The solid line is highest at ages 35 to 39, inclusive, whereas the broken line, representing contributions of lesser average merit, attains its peak five years later, namely, at ages 40 to 44, inclusive.

Some readers may wonder whether the differences in the shapes of the curves (Figs. 1 and 2) which set forth quality versus quantity of output may not be due, in part at least, to the fact that different groups of workers produced the contributions called "supe-

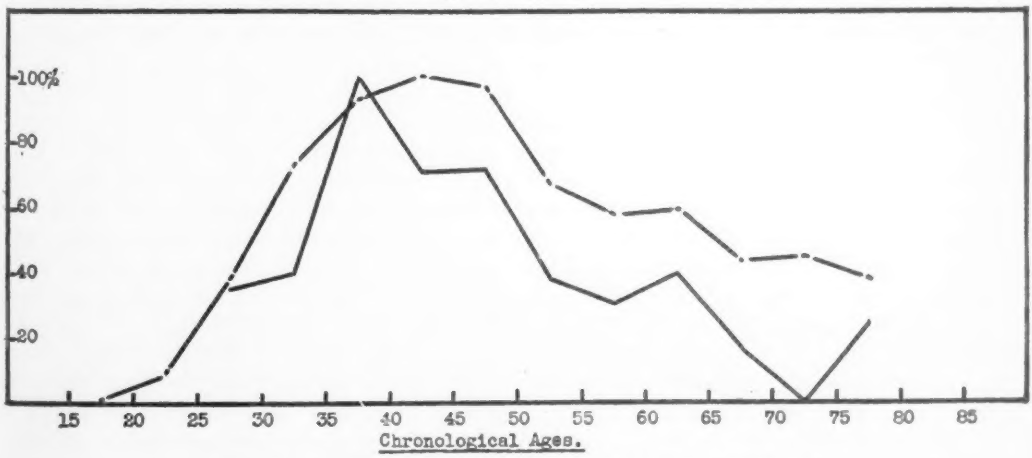


FIG. 2. AGE VERSUS PRODUCTION IN PSYCHOLOGY
Solid line, 85 SUPERIOR CONTRIBUTIONS BY 50 MEN, NOW DECEASED, AVERAGING 1.70 PER CONTRIBUTOR. *Broken line,* 4,687 OF LESSER MERIT BY 339 CONTEMPORARY PSYCHOLOGISTS, AVERAGING 13.82 PER MAN.

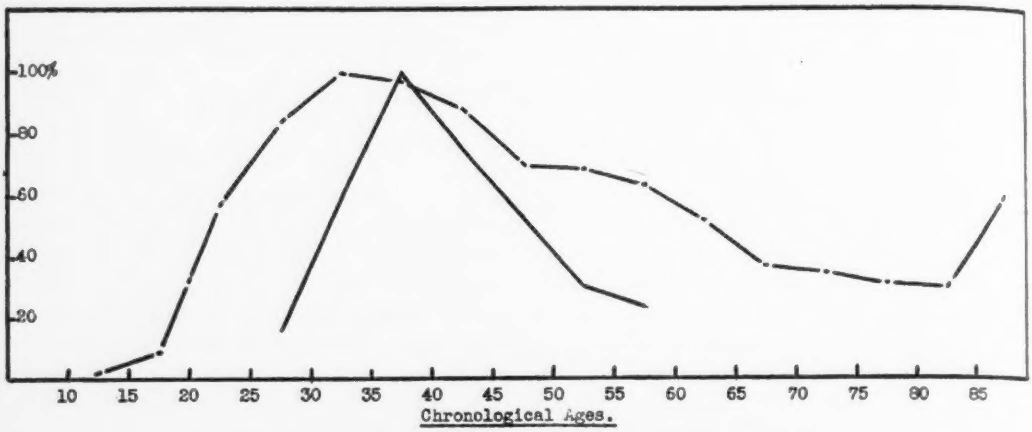


FIG. 3. AGE VERSUS PRODUCTION OF GRAND OPERAS
Solid line, THE ONE BEST-LOVED GRAND OPERA BY EACH OF 51 COMPOSERS WHO ARE NO LONGER LIVING.
Broken line, 532 GRAND OPERAS BY THE SAME 51 COMPOSERS, INCLUDING OPERAS NOT OFTEN PERFORMED.

rior" and those labelled "of lesser merit," respectively. The data in the following examples indicate that the foregoing hypothesis is of doubtful validity.

Grand Opera. In Figure 3 the solid line sets forth the chronological ages at which each of 51 composers, now deceased, produced his one best-loved grand opera; the broken line presents the ages at which *these same 51 men* produced a total of 532 grand operas.[6]

A word of explanation as to how the best-loved grand operas were identified may be in order at this point. With NYA student assistance, which was essential for the completion of this study, the present writer made a composite study of 15 different books each of which was alleged by its author to contain a select list of those operas that possess lasting merit and that opera-goers are most likely to hear. Analysis of the 15 books was made on the assumption that an opera listed in many different books, which contain so-called "favorite" operas, is likely to be more popular than is another opera by the same composer which is listed in only a few such books. In the construction of the solid line of Figure 3 no opera was used unless it appeared more frequently than any other opera produced by the same composer.

It will be noted that the solid line attains its peak at ages 35 to 39, inclusive, whereas the broken line attains its peak five years earlier. The earlier rise of the curve for quantity of output suggests that the grand opera composer must have a practice period prior to the accomplishment of his best work.

Short Stories. In Figure 4 the solid line presents the ages at which 87 best-liked short stories were either written or first published by 38 authors, now deceased. The stories selected were those that appeared most often in 102 books of favorite short stories. No story was included unless it appeared in 4 or more of the 102 source books.

The broken line presents the chronological ages at which 416 other short stories were produced by the *same 38 authors* who wrote the 87 best-liked ones. Age data were obtained from Jessup.[7]

Although the peaks of both curves are rather narrow, the peak of the solid line is more pointed than that of the broken line. It should be realized that the abrupt drop of the former curve does not signify that either individual or group proficiency declines at the same rapid rate. The solid line was so constructed as to reveal merely the number of peak performances which were attained at successive chronological age levels. Hence, a number of short stories only very slightly inferior to some of those used in the construction of this line have received no credit at all. If fractional credit were awarded for these just noticeably inferior short stories, the solid line would rise and fall more gradually. Its sudden rise and abrupt descent indicate, therefore, merely a consid-

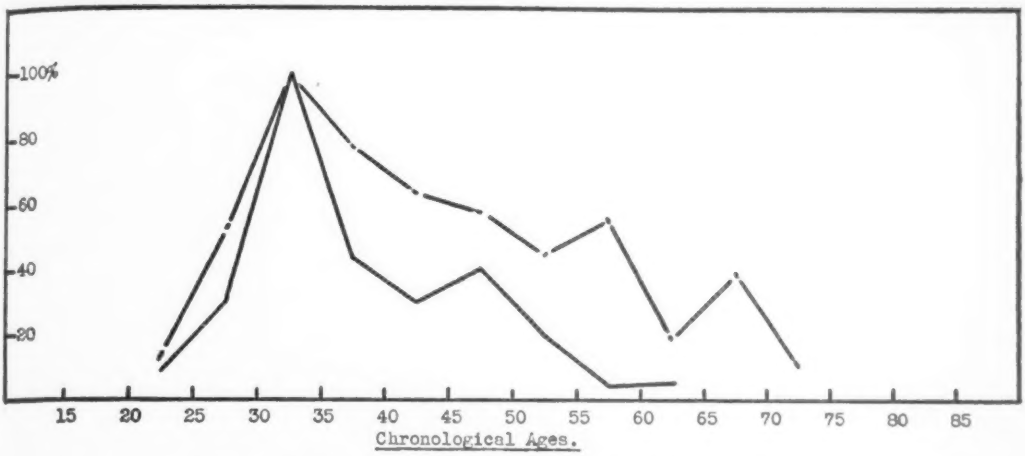


FIG. 4. AGE VERSUS PRODUCTION OF SHORT STORIES
Solid line, 87 SUPERIOR SHORT STORIES BY 38 AUTHORS, NOW DECEASED, AVERAGING 2.29 PER PERSON.
Broken line, 416 SHORT STORIES OF LESSER MERIT BY THE SAME 38 AUTHORS, MEAN 10.95 PER PERSON.

erable degree of certainty that man's productive prime for short stories of the highest excellence has really been ascertained.

Hymn Poems. The solid line in Figure 5 sets forth age data regarding the one best-loved poem, sung to church hymn tunes, written by each of 63 poets, now deceased. No poem was used in constructing the solid line unless it appeared in 10 or more of 20 church hymnals that were canvassed. And none was used unless it appeared in more hymnals than any other poem by the same author. The broken line presents like information regarding the composition of 298 other poems written by the *same 63 poets.* All the age data set forth in Figure 5 were obtained from a composite list.

It will be noted that the peak for quality of output occurs at ages 30 to 39, inclusive, and that the peak for quantity of output occurs ten years later. All these curves seem to refute the idea that genius functions equally well throughout the years of adulthood. But, of course, these findings are merely group averages and they are not directly applicable to all individuals. As is well known, some persons have made their most valuable contribution when past seventy years of age, and others have done very notable work while still in their teens. In addition one should bear in mind that

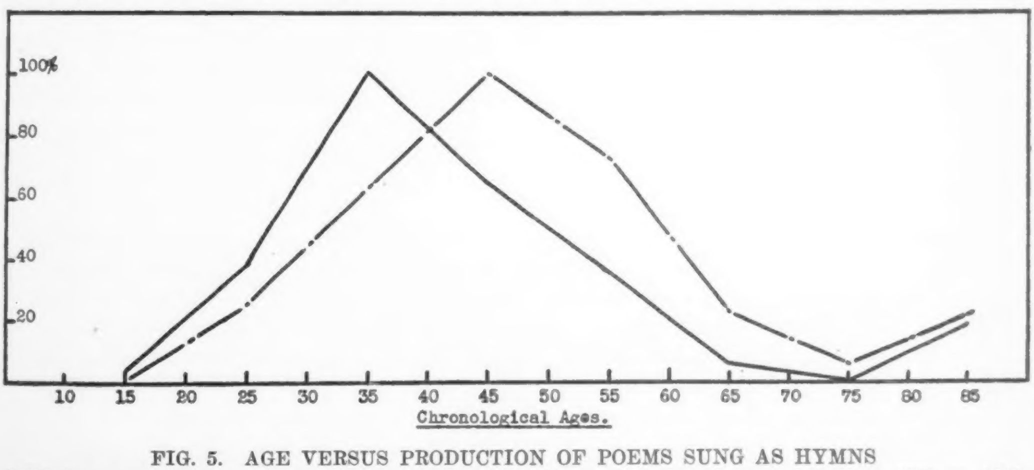


FIG. 5. AGE VERSUS PRODUCTION OF POEMS SUNG AS HYMNS
Solid line, THE ONE BEST-LOVED POEM BY EACH OF 63 PERSONS WHO WERE BORN FROM 1800 TO 1849.
Broken line, 298 SIMILAR POEMS OF LESSER POPULAR APPEAL WRITTEN BY THE SAME 63 INDIVIDUALS.

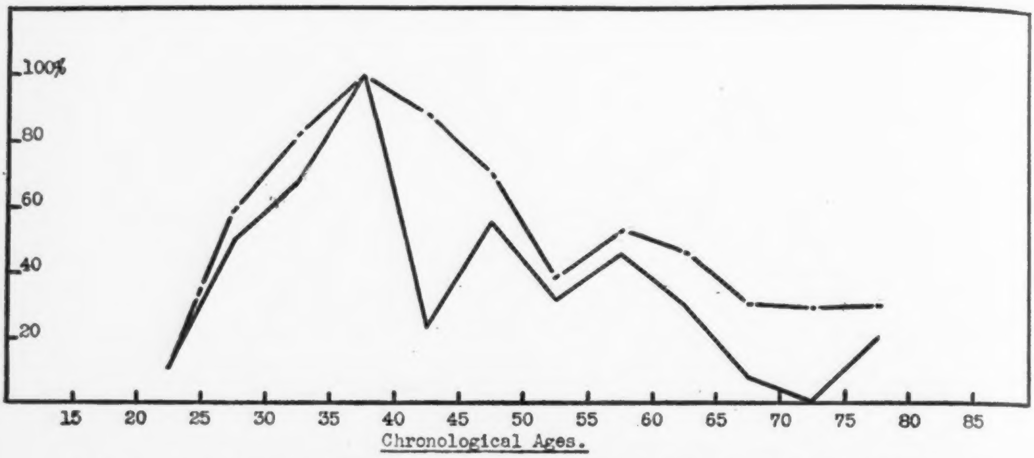


FIG. 6. AGE VERSUS PRODUCTION IN EDUCATIONAL THEORY AND PRACTICE
Solid line, ONE SUPERIOR CONTRIBUTION BY EACH OF 75 PERSONS WHO WERE BORN FROM 1750 TO 1850.
Broken line, 425 CONTRIBUTIONS OF LESSER QUALITY FROM 206 INDIVIDUALS BORN FROM 1750 TO 1850.

throughout almost their entire lives very superior individuals may do work of higher quality than the very best work that is accomplished by men of lesser talent. The mere fact that a man has passed his own productive prime does not signify that he will no longer produce work of very great value to society.

Education. The solid line of Figure 6 shows the ages at which each of 75 individuals, now deceased, produced his one most frequently cited educational treatise, report, or plan for the improvement of educational practice. No contribution was used unless it was cited and discussed in 3 or more of 49 histories of education that were employed as sources of information. The broken line sets forth information regarding the production of 425 educational contributions by 206 persons, now deceased. The period of maximum production is the same in both curves.

Economics and Political Science. In books which deal with the history of economics and political science there is so much overlapping of these two fields that it seemed inadvisable to attempt to separate them. The solid line in Figure 7 presents for both economics and political science, therefore, the one most frequently cited book by each of 62 men, now deceased. No work was included unless it

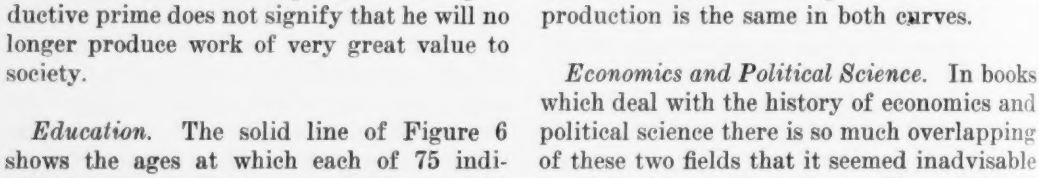


FIG. 7. AGE VERSUS PRODUCTION IN ECONOMICS AND POLITICAL SCIENCE
Solid line, ONE SUPERIOR CONTRIBUTION BY EACH OF 62 INDIVIDUALS BORN BETWEEN 1750 AND 1850.
Broken line, 234 OTHER CONTRIBUTIONS OF LESSER SIGNIFICANCE WRITTEN BY THE SAME 62 PERSONS.

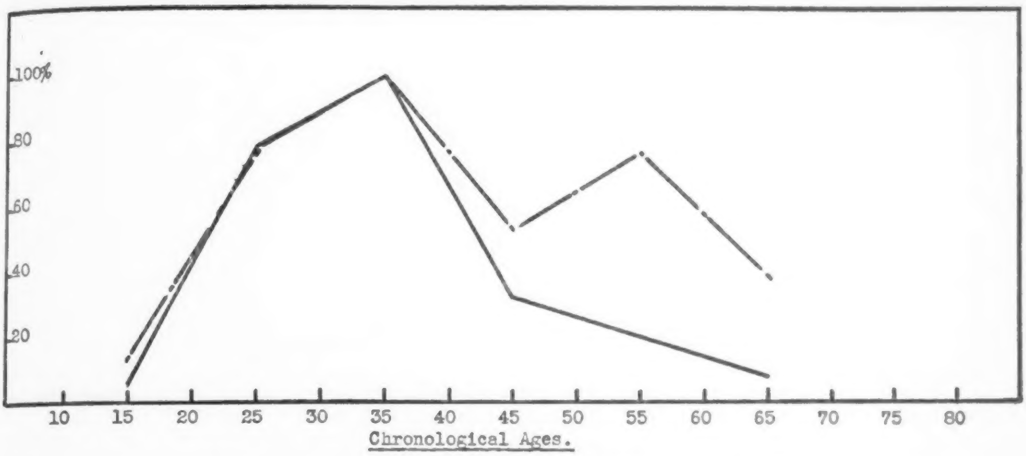


FIG. 8. AGE VERSUS PRODUCTION IN MATHEMATICS
Solid line, 42 SUPERIOR CONTRIBUTIONS FROM 27 MATHEMATICIANS WHO WERE BORN FROM 1748 TO 1848. *Broken line,* 169 OTHER CONTRIBUTIONS OF LESSER IMPORTANCE PRODUCED BY THE SAME 27 INDIVIDUALS.

appeared in 5 or more of 20 histories of economics and political science that were canvassed. The broken line presents for the *same 62 deceased men* the ages at which they either wrote or first published 234 other works in the same fields of endeavor. It is again apparent that quantity of output continued to appear at later age levels than did work of the highest quality.

Prior to constructing the broken line in Figure 7, the present writer submitted the solid line to a college dean and asked his opinion as to why this curve for output of high quality attains its peak at such a relatively youthful age level and descends so rapidly thereafter. The dean suggested that men are likely to possess more time for doing creative work when they are young. By way of illustration he stated that as a young instructor he was less preoccupied than he is at present; now his hands are so tied by administrative duties that he can find no time at all for creative endeavor.

Mathematics. In Figure 8 the solid line is based upon 42 mathematical contributions by 27 mathematicians,[8] now deceased. The broken line presents the ages at which a total of 169 contributions were made by these *same 27 mathematicians.*[9] Although in their ascents the two curves in Figure 8 almost coincide, the curve for the larger number of contributions sustains itself much better at the older age levels.

Invention. In an article[10] entitled "Age of Production in Invention and Other Fields," Wyman asserts that for the 20 greatest inventions of modern times, the average age of the inventors at the time of making their notable inventions is 32. He adds that, if the list is enlarged to include the 40 greatest inventions, the average age of the inventors rises to 33.3 (see the solid line in Figure 9). He says also that, if the list is still further enlarged to include the 80 greatest inventions, the average age of production moves up two more years.

Although one may doubt that Wyman is able to measure the importance of a particular invention with as much precision as his statements imply, the age-curves that are presented herein suggest, nevertheless, that Wyman's foregoing assertions contain an element of solid truth. By assembling a list of 554 great inventions, the present writer went one step further in his calculations than Wyman did and found that the average age of the inventors moved upward still farther than Wyman's highest average, namely, to 36.71 years (see the broken line in Figure 9).

The reason why inventions of slightly less than the very highest quality are more likely to appear beyond, rather than before, the optimum age of 32 is more easily understood after inspection of the age-curves presented herein. The average person seems to develop to the peak of his efficiency much more rapidly than he descends therefrom. Therefore,

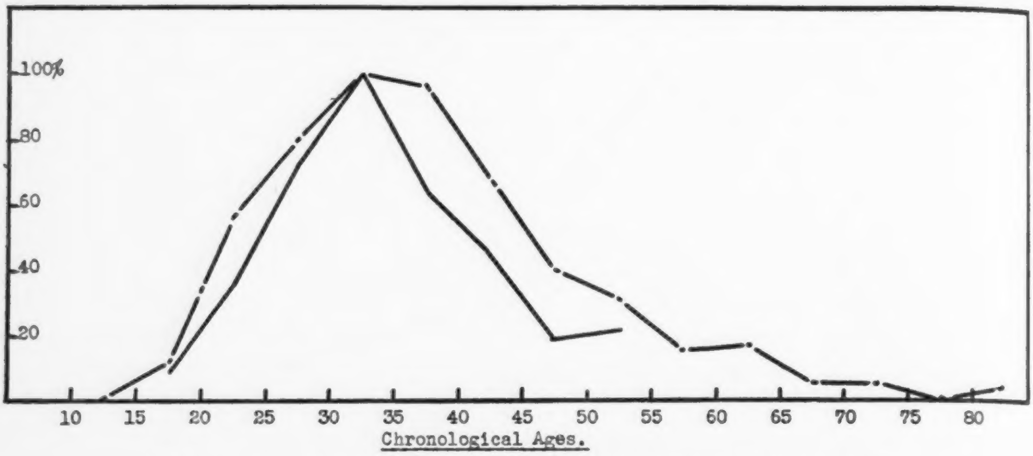


FIG. 9. AGE VERSUS PRODUCTION OF PRACTICAL INVENTIONS
Solid line, 40 GREATEST PRIMARY INVENTIONS OF MODERN TIMES PRODUCED BY 35 MEN NOW DECEASED.
Broken line, 554 INVENTIONS OF LESSER SIGNIFICANCE PRODUCED BY 402 INDIVIDUALS NOW DECEASED.

the period beyond that of peak efficiency is likely to be both of longer duration and also much more productive as regards sheer quantity of output than is that very much shorter interval of time during which man is "on the make," so to speak.

But Wyman's finding with reference to the ages of inventors is an insufficient basis upon which to generalize, and Wyman wisely refrained from doing so. The present writer has found that the average age of a group of contributors of works of less than the highest merit may be older than, younger than, or exactly the same as the optimum age level at which work of the very highest quality tends most often to appear. As regards age variability among contributors, the findings are much more consistent. For athletes,[11] and for creative thinkers of many kinds—scientists, philosophers,[12] authors[13] of "best books," painters[14] in oil, and others, the very best achievements are executed at ages which deviate less from the optimum age level for accomplishing than do performances of lesser average merit.

Hymn Tunes. It is also true that the one most outstanding work of each of the most brilliant creative thinkers is likely to be accomplished during a narrower age range than is the one most notable work of each of the less renowned creative thinkers. For example, each of the three curves of Figure 10 presents the ages at which the most popular church hymn tunes were composed by each of 131 individuals segregated upon the basis of the popularity of their one best-liked hymn tune. The data were assembled by Mrs. Ruth Burt Korb as part of her Master's Thesis. The solid line presents age data for those composers whose one best-loved hymn tune appeared in 10 or more of 20 church hymnals that were canvassed by Mrs. Korb; the broken line presents age data regarding other composers whose one best-loved hymn tune appeared in from 4 to 9 church hymnals, and the dotted, or dash, line sets forth age data for still another group of composers whose one best-liked hymn tune appeared in from 1 to 3 church hymnals.

Although each of the curves attains its peak at ages 30 to 39, inclusive, the curve which presents age data for the most popular group of compositions exhibits a sharper peak and also a narrower range than does the curve which presents data for the least popular group of hymn tunes (the dash line). The fact that the two curves of Figure 10 which set forth age data for the less popular groups of hymn tunes each persist until beyond age 70 suggests that, although a hymn tune that is either written or first published beyond age 70 may be a particular composer's one best hymn tune, such a tune is not likely to be chosen for publication in many church hymnals. Since the foregoing phenomenon has been found to occur in several different fields of endeavor, it seems

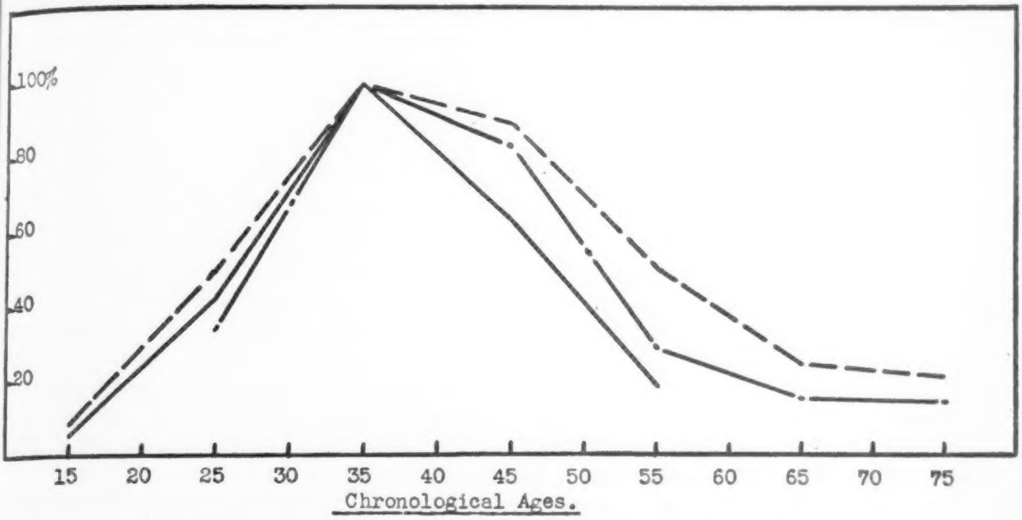


FIG. 10. AGE VERSUS PRODUCTION OF HYMN TUNES
THE ONE BEST-LOVED HYMN TUNE BY EACH OF 131 COMPOSERS, BORN FROM 1815 TO 1850. THESE TUNES ARE PLACED IN THREE CATEGORIES OF POPULARITY: *solid line*, 42 FOUND IN 10 OR MORE OF 20 HYMN BOOKS; *broken line*, 51 FOUND IN 4 TO 9 OF THE SAME HYMNALS; *dotted line*, 38 FOUND IN 1 TO 3 OF THE SAME.

reasonable to conclude that the best and most brilliant creative accomplishments are the work of individuals who "hit their stride" at not too old an age level.

Chemistry. In Figure 11 the solid line presents age data for 52 very superior contributions which are listed in Hilditch's *A Concise History of Chemistry*,[15] and which also were selected by two out of three university chemistry teachers as among the 100 greatest contributions to chemistry of all time. The broken line presents age data for 993 contributions, all of which were regarded by Hilditch as of sufficient importance to warrant their inclusion in his history of chemistry. The dash line sets forth data for 6,743 contemporary contributions (articles, patents, and books). Age data regarding the contemporary contributions were obtained in

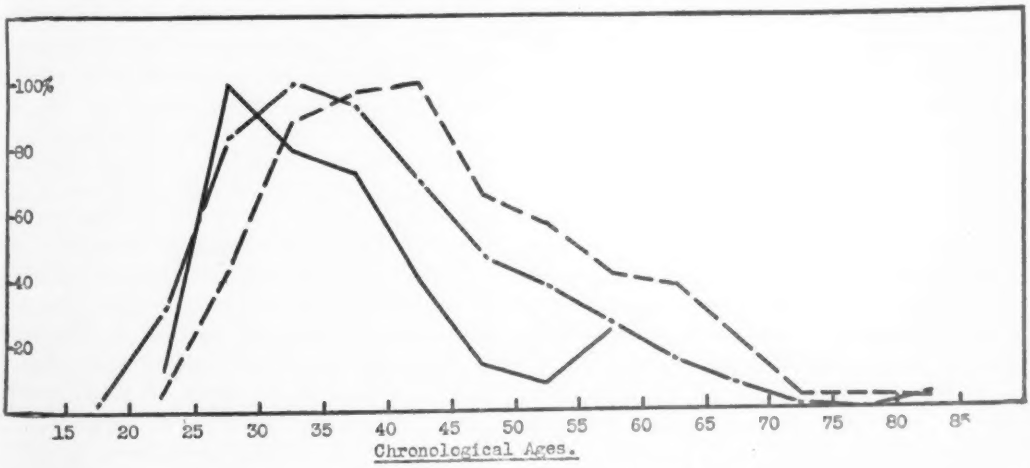


FIG. 11. AGE VERSUS OUTPUT IN CHEMISTRY
Solid line, 52 OF THE GREATEST CHEMICAL DISCOVERIES, MADE BY 46 MEN NOW DECEASED. AVERAGE 1.13.
Broken line, 993 CONTRIBUTIONS OF LESSER MERIT MADE BY 244 CHEMISTS NOW DECEASED. AVERAGE 4.07.
Dotted line, 6,743 RUN-OF-THE-MINE CONTRIBUTIONS BY 1,136 CONTEMPORARY CHEMISTS. AVERAGE 5.94.

the following manner. The names of the contemporary chemists and their birth dates were found by canvassing the 1933 edition of *American Men of Science*[16] from the letter A to Gr, inclusive. A sample of the contributions of these contemporary chemists was then obtained by canvassing *Chemical Abstracts* for the years 1920 to 1922, inclusive, and also for the years 1930 to 1932, inclusive.

In several respects Figure 11 reminds one of Wyman's assertions with reference to the ages at which great inventions are most likely to be made. Thus, the curve which presents age data for the 52 contributions of the highest merit ascends most rapidly, attains its peak earliest, and falls off earlier than do either of the other two curves. The curve in Figure 11 which presents age data for contributions assumed to be of the least average merit rises latest, attains its peak latest, and also falls off later than do either of the two other curves in this figure.

One might conclude that the "brainiest" chemists tend to use their brains with maximum effectiveness at the earliest opportunity. This tendency on the part of scientific giants to develop to the peak of their efficiency at relatively youthful age levels presents a baffling problem to the investigator who wishes to ascertain with great precision man's one most creative year. Any study that concerns itself with achievement of the very highest quality must of necessity include a very restricted number of achievements within each separate field of endeavor. But, the smaller the number of cases, the larger the probable error and, hence, the less trustworthy the finding.

It is true, to be sure, that for the contemporary contributions two time-lags occurred between date of achievement and date of appearance in *Chemical Abstracts*. But, since citation in *Chemical Abstracts* occurs usually within less than a year subsequent to first publication, it seem unlikely that difference in time-lag can account entirely for the relatively late age levels at which contemporary contributions are being made in chemistry.

Some may wonder whether the curves in Figure 11 may not merely indicate that epoch-making discoveries in the field of chemistry are being made today at older age levels than was formerly the case. With this possibility in mind the writer made an exhaustive analysis of the three sets of data obtained by requesting three university chemistry teachers to select the 100 greatest chemistry contributions of all time. It was found that 50 per cent of those born from 1820 to 1850 had made their outstanding contributions at slightly younger, but not significantly different, average ages than had the chemists born earlier.

Since the more recently born chemists have not made their most notable chemistry contributions at older average age levels than the earlier born chemists, why do the three curves in Figure 11 ascend in the order indicated rather than in the reverse order? If the drive to accomplish weakens with advancing years, this in itself may be an indissociable age effect. If so, it is idle to argue that the fifty-year-olds *could* have attained a better average output than the thirty-year-olds if the former had wanted to do so badly enough. It is likewise idle to argue what might have happened under any other hypothetical condition which conceivably might have existed but which actually did not exist.

Conclusions. Study of the graphs presented herein seems to justify the following tentative generalizations. (1) Within any given field of endeavor, not one only, but numerous age-curves can be constructed which show the rise and fall of creative output at successful age levels. (2) The shape of any one of these various curves is in part a function of quality of performance. (3) As compared with an age-curve which sets forth quantity of performance at successive age levels, the peak of a curve which presents age data for performances of the highest quality is likely to be more narrow or pointed. (4) Within any given field of endeavor, quality of output and quantity of output are not necessarily correlated, output of the very highest merit tending to fall off at an earlier age level than does output of lesser merit. (5) Since quality of output and quantity of output are imperfectly correlated, no very accurate comparison of the ages of greatest creative efficiency in the several fields of science can be made unless the contributions are first equated upon the basis of their quality.

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ERYTHROS

From marrow web, its nuclear center lost
As it was born into the plasmal flood,
A hemoglobin-bearing disc of blood
Begins a restless journey through its host.

Equipped to carry pulmonary aid
To cells in want of oxygen
On many metabolic fronts and lend
Its bulk to keep the capillary grade.

A thousand circuits daily for one moon
To splenic journey's end or Kupffer's aisle
By trillions fragile shells reduced to bile,
A bitter souvenir of verdant doom.

Itself not living, symbolizing life
In "blood will tell" or other genic phrase
As culled from records of an endless fight,
A plastid form ubiquitously rife,
Subservient, efficient, clad in lucent grace,
The thermic mammal's blond erythrocyte.

—JOHN G. SINCLAIR

SCIENCE ON THE MARCH

FOSSIL PIGMENTS*

BIOCHEMICAL chapters of the ancient past are suggested by the presence of numerous organic pigments of well-defined properties in natural deposits of thousands of years' standing. Chlorophylls occur throughout the world of green plants, accompanied by the red, orange, or yellow fat-soluble members of the carotenoid series, whose colors are masked in green leaves and in many unicellular algae, but are familiar to all as extravagantly displayed in many flower-parts, fruits, certain autumn-colored leaves, and in some roots, such as the carrot. Many carotenoids are synthesized also by bacteria and fungi. Pigments of the same class are assimilated from food and stored in the skin, liver, fat, milk, eggs, and other tissues or products of innumerable animals. Many carotenoid compounds are present in the vast populations of microscopic plankton organisms of the sea, and are conspicuous also in various tissues of the larger plants and animals found there. It was the impressive display of carotenoids in many obligately carnivorous or detritus-feeding animals of the ocean's unlighted depths, destitute of living photosynthetic plants, which gave the initial impetus to the writer's search for supplies of such pigments in bottom sediments.

In natural deposits of moderately great age, such as those of certain moor soils, muds from lakes, marshes, underground caves, and notably deep-lying sediments of the ocean floor, molecular fragments of chlorophyll and of animal homologues, such as the hemin of hemoglobin, still persist as various porphyrins. These occur side by side with various carotenoids, although the marine carotenoids appear to decrease with age (depth of stratum) just as does total organic matter.

In organic fossils of great ages (e.g., petroleum, shale oils, and coal) porphyrins occur, but are no longer accompanied by carotenoids, these having been long since oxidized, or, under appropriate conditions, perhaps reduced to colorless hydrocarbons.

Thus, progressing from living material to fossil substances of increasing age, complex molecules such as chlorophyll and hemin are the first pigments to undergo degradation, persisting for but a very short time after the death of organisms; carotenoids are represented in anaerobic deposits of great age in a biochemical sense, i.e., thousands of years, antedating even the Pyramids of Egypt; and these intermediary fossils are in turn outlasted by the porphyrin fragments of the original more complex pigments; some of these porphyrins persist into eons of geological time. Various chlorophyll- and hemin-derivatives in bituminous rocks, petroleums, mineral waxes, asphalts, and other fossilized materials have been extensively discussed by others. The present discussion is concerned primarily with the occurrence of carotenoids in sediments recovered from ancient burial in the bottom of the sea.

Let one haul up a solid cylindrical column of mud, collected from the ocean floor with a special coring device, draw off the superficial water, submit the sample preferably to further drying in an evacuated container, and subsequently treat the material repeatedly with appropriate organic solvents such as acetone or alcohol. The filtered extracts show deep green-brown, greenish orange, or yellow colors depending on the proportions and relative concentrations of chlorophyll break-down products and carotenoids present. No unaltered chlorophyll is encountered, but numerous derivatives of it are separable. A number of different carotenoids are always present, including hydrocarbons of the $C_{40}H_{56}$ series, and so-called polyene alcoholic or ketonic derivatives, wherein from one to six or more oxygen atoms have entered the molecular constitution to give $C_{40}H_{56}O$, $C_{40}H_{56}O_2$, etc.

The carotenoids as a class are chemically unstable, their crystals or solutions undergoing ready bleaching by atmospheric oxygen. This destruction is enhanced by the presence of light and by elevated temperatures. Carotenoids are also destroyed by acids and in some cases by alkalies. The natural preservation of such ordinarily labile

* Contributions from the Scripps Institution of Oceanography, New Series No. 239.

compounds over vast ages of time is less surprising, however, when one considers the very special conditions prevalent in buried strata of the ocean's floor. For there, free oxygen is lacking, light is absent, temperatures perpetually approach 0° C., and approximate neutrality, approaching that of body fluids, persists. And, while native chlorophylls are readily broken down to their still-pigmented residues by ordinary chemical or biochemical processes, carotenoids are altered or absorbed in the digestive tracts of most animals only at low levels of efficiency. Thus they may pass again and again through the alimentary canals of various mud-eating animals in a chemically unaltered state. Even those which are assimilated may be stored in the consumers' tissues in a but slightly modified or unchanged condition. Furthermore, carotenoids are relatively refractory toward the ordinary nonoxidative biochemical processes of such environments.

The ultimate food supply of benthic animals is in the slow, ceaseless rain of organic matter from lighted zones above. The constant manufacture and supply of carotenoids by diatoms, dinoflagellates, and other marine photosynthetic plants and by certain fungi and bacteria, exceeds the power of animals and microorganisms to assimilate or destroy these pigments. Hence certain parts of the sea bottom have become vast reservoirs for such compounds, which are gradually buried under conditions favoring their preservation over centuries of time.

Preliminary quantitative studies have revealed that, while finely suspended marine detritus may contain as much as 50 mg. of total carotenoids per 100 grams dry weight of material, or 165 mg. of carotenoids per 100 grams of ash-free organic matter involved, marine sediments off the coast of southern California yield amounts of the general order of 0.25 mg. per 100 grams of dry mud, or roughly 10 mg. per 100 grams organic matter in such sediments. This mean figure approximates those of investigated sediments lying 106, 650, and 1,096 fathoms beneath the ocean surface, and to mud strata varying in age between about 15 and 2,500 years. The same pigments have been demonstrated in far older deposits as well. The pigments seem to be present at slightly higher concentrations at the top of the mud than in the deeper-lying strata, and this is to be expected, since any processes of decomposition will have been operative longer in the older material.

Quantitative and qualitative variations are encountered. At one station, for example, material collected from the surface of the ocean floor under 106 fathoms of water, yielded 0.17 mg. of carotenoids per 100 grams of dried material; the first, second, and third foot of a vertical core collected there, representing accumulations of not more than 200, 400, and 600 years respectively, yielded 0.24, 0.06, and 0.05 mg. per cent; the fourth foot of this core, representing an estimated maximal age of 800 years, appeared to contain only about 0.03 mg. per cent. On the other hand, sediment collected at a point not far distant, at a depth of 650 fathoms beneath the water surface yielded, from the eight-foot mud-depth of the core (estimated age = 2,500 years) 0.29 mg. per cent of the carotenoid material. One core, collected from the bottom of the Gulf of California at a depth of 364 fathoms, was 17 feet long. A section of this column of mud, cut from the 15- to 16-foot depth, yielded some 0.61 mg. per cent of carotenoids from the 6,000 to 7,000-year-old stratum.

All marine sediment cores yield greenish porphyrin derivatives as well as carotenoids, the more rapidly deposited material in the Gulf of California being substantially richer in both types of molecular fossil. One core of oceanic sediment was remarkable in its pigmentary stratification. While carotenoids, accompanied by greenish porphyrins, were recovered from the 6-inch, 74-inch and 80-inch depths of this sample (representing approximate respective ages of 600, 7,000, and 8,000 years), an intermediate section of the same sample, taken at the 44-inch depth (about 4,000 years old) contained the greenish porphyrin common to all the sections (absorbing light in the red region of the spectrum at about 669 mμ in petroleum ether), but unaccompanied by any carotenoids. Instead, an oily fraction was encountered, containing a yellowish pigment showing blue-green fluorescence, closely similar in this respect, in spectral absorption and in critical

chemical behavior to a pigment obtained from a sample of California crude petroleum, and similar also to a porphyrin from asphalt.

Perhaps equally as arresting as the fact itself of age-long preservation of carotenoids are the qualitatively selective processes which become evident on chemical examination of the constituent pigments. For, while the xanthophyllic or oxygenated type of carotenoid is greatly preponderant over the hydrocarbon or carotene class in all terrestrial and marine green plants, as well as in the vast majority of marine animals, the proportionality has undergone a reversal in the fossil domain. As examples, various seaweeds may contain carotenes in the order of from 5 to 25 per cent of total carotenoids; microscopic dinoflagellate plants such as *Prorocentrum micans,* and diatoms such as the common *Nitzschia closterium,* both of which occur in vast numbers in the sea, have been found to yield only about 10 per cent of their total carotenoids as carotene, the remaining 90 per cent belonging to the oxygenated or xanthophyllic class. Again, the stores of carotenoids in finely suspended marine detritus or "ocean refuse" are approximately 90 per cent xanthophylls. The great majority of marine animals examined to date reveal their capacity to store carotenoids of the xanthophyllic class with a high degree of selectivity. Indeed, numerous fishes, mollusks, and echinoderms, for example, contain xanthophylls or their chemical esters exclusively, rejecting carotenes in their feces or otherwise disposing of these pigments instead of storing them.

Turning back to the sediments, we encounter there proportions of the hydrocarbon carotenoids ranging from 35 to 40 per cent in the topmost layers of mud, to 70, 80 and even nearly 90 per cent in deeper strata. The 2,500-year-old sample, for instance, yielded 83 per cent of its carotenoids as carotenes, and, in the 6,000- to 7,000-year specimen from the long Gulf of California core, carotenes exceeded xanthophylls by a ratio of more than 2 to 1.

Chemical investigations have indicated that the chief member of the carotene class in marine sediments is the common pro-vitamin A compound, beta-carotene, with pigments resembling alpha-carotene in secondary prominence. These are frequently accompanied by other hydrocarbon types of carotenoid.

Among the xanthophylls of marine muds, compounds not readily distinguishable from the common pigment zeaxanthin, encountered notably in yellow Indian corn, are the most common. These sedimentary pigments are probably identical with certain newly described xanthophylls occurring in diatoms and other marine plants. Fucoxanthin, common in kelps and other algae, is abundant in sedimentary material, as are other less common xanthophylls from algae. Sulcatoxanthin, or peridinin, occurring both in some of the microscopic algae and in certain sea-anemones, is another xanthophyll found prominently in sediments.

The general preponderance of carotenes over xanthophylls in long-standing marine deposits constitutes a reversal of the status prevailing in the great majority of marine organisms. This condition in sediments may have its explanation in several potential factors. In the first place, xanthophylls are more readily oxidized and bleached by atmospheric or dissolved oxygen than are carotenes. While this differentiative influence might be operative even in the deeper realms of the ocean's water, it would not apply beneath the surface of the oxygen-free mud. Secondly, the majority of marine animals investigated store chiefly xanthophylls rather than carotenes in their tissues; their storage and partial degradation of polyene alcohols, with fecal rejection of carotenes could contribute substantially to a gradual preponderance of the latter class of carotenoid in bottom sediments. Finally, there are indications that certain kinds of bacteria and allied microorganisms living in marine muds may contribute carotenes of their own synthesis, and that other such flora may be able to effect the chemical reduction of xanthophylls to compounds of decreased oxygen content, or perhaps even to carotenes.

These ancient biochromic compounds, including porphyrins and carotenoids, together with accompanying oil-soluble substances, may be looked upon as diagnostic features in the continued search for biochemical processes operative in the genesis of petroleum and allied natural deposits.—DENIS L. FOX.

BOOK REVIEWS

PLASTIC HORIZONS

Plastic Horizons. B. H. Weil and Victor J. Anhorn. 169 pp. Illus. $2.50. 1944. The Jaques Cattell Press, Lancaster, Pa.

WHILE this modest volume (150 pages) suffers in a few places from the technical man's traditional difficulty in converting his scientifically calibrated thoughts into easy and sparkling phrases intriguing to the lay reader, it is on the whole a very readable, well-planned, and carefully executed work.

Divided into five sections, the first, dealing with the various types of plastic materials, their history, chemical formulation, and most prominent characteristics, may prove somewhat cumbersome to the person of little or no chemical knowledge, but it is valuable and necessary to an adequate understanding of the subject. The authors have, on the whole, done an excellent job in simplifying some extremely complex material. Freed of this necessary groundwork, the volume rides much more easily through a general picture of the plastics industry, its problems and accomplishments, military and civilian applications of plastic materials, synthetic fibers and synthetic rubbers, and the prospects for plastics in the postwar era.

While semitechnical books on the subject of plastics have become numerous during the past few years, the sincerity with which Messrs. Weil and Anhorn have attacked the problem is outstanding. Not content with the usual "cataloging" of plastic materials supplemented with a few historical notes and predictions, the authors of *Plastic Horizons* have carefully traced the complex network of economics, technical problems, availability of and competition for raw materials, patent restrictions, and innumerable other factors which have influenced the development of the plastics industry to its present state, and which will guide the course of these materials and their manufacturers in the future.

The volume also takes up at some length the various synthetic fibers and synthetic rubbers, their sources, qualities and potentialities, and their kinship to plastics, a relationship not generally appreciated.

As to the future, the authors make some very sound predictions which, as a matter of fact, scarcely need stating for readers who have at this point become so thoroughly familiar with the plastics field, in its broadest sense, that they should have almost unconsciously arrived at these same conclusions. This, perhaps, is the test which reveals the inherent worth of the book.

While this volume would benefit substantially by the addition of a few well-selected photographs, it does contain a number of excellent charts and diagrams which are of greater intrinsic merit. Valuable as a reference is an appendix listing approximately three hundred plastic trade names and indicating their basic chemical type and manufacturer.

Plastic Horizons should serve well as a reference, as a beginning text, and as a worthy addition to the bookshelf of any layman who would have more knowledge of the plastics picture than the shallow ability to recite names and formulas.—L. H. WOODMAN.

PIONEER GEOLOGIST

David Dale Owen, Pioneer Geologist of the Middle West. Walter Brookfield Hendrickson. Illustrated. xiii + 180 pp. $2.00. 1943. Indiana Historical Bureau.

A HUNDRED years ago David Dale Owen was one of the leading geologists of the United States. He was of the second generation of scientists who made New Harmony, Indiana, their home. He was a son of Robert Owen, the well-known industrial and social reformer, and followed the trail blazed by such men as William Maclure, Thomas Say, Gerard Troost, and Charles Alexander Lesueur. Although David Dale Owen was a chemist of no mean accomplishment, it was as a geologist that he made his claim to fame. He was born near New Lanark, Scotland, June 24, 1807. He was educated in Scotland, England, and Switzerland and specialized in mathematics and science. He came to America in 1828, and was graduated as doctor of medicine in 1837 from the Medical College of Cincinnati. In the same year he was married to Caroline Neef. Shortly thereafter he became connected with the State geological survey of Tennessee under

Gerard Troost, was State geologist of Indiana in 1837–38, and made surveys of the Dubuque and Mineral Point districts of Iowa and Wisconsin in 1839–40. In 1847 he was appointed United States geologist and was directed to make a survey of the Chippewa land district. In 1854, he was appointed State geologist of Kentucky; in 1857, State geologist of Arkansas; in 1859, he was appointed for the second time State geologist of Indiana. He died at New Harmony, Indiana, November 13, 1860. During his lifetime, in charge of pioneering surveys of three states and three territories, he gave the world the first connected picture of the rock structure and the mineral wealth of the Upper Mississippi Valley and laid the groundwork for later geological investigation. Although he was well and favorably known to his fellow geologists and to contemporaries interested in the natural resources of the middle western United States, Dr. Owen's name and deeds are not now so well known to most present-day students. It is the purpose of this biography to revive his memory and to give him his rightful place in the history of science. Biographies of America's lesser scientists are all too few, and the history of scientific advance in the United States can never be fully told or entirely understood until we know more about the numerous, hardworking, modest men like Dr. Owen, who devoted their lives to scientific research. American science is indebted to Professor Hendrickson and others like him who from time to time have made biographical contributions such as this to its records.—J. S. WADE.

MIDDLE AMERICA

Middle America. Charles Morrow Wilson. 317 pp. Illus. $3.50. 1944. W. W. Norton & Co., Inc., New York.

MR. WILSON has been writing on our neighbors to the South for some time and *Middle America* is probably his most ambitious attempt. He sets out to tell us about these nearest neighbors because of their significance to us. Thirty-seven million Americans living in an area a third the size of the United States who are, as Mr. Wilson states it, by odds our best customers, require more understanding than we have applied to them in the past. The extent to which we depend on this area for quality coffees, bananas and sugar and the extent to which we could draw on them for rubber, rotenone insecticides, quinine, and other tropical products, are factors in our national life and international policy which we cannot continue to neglect.

Mr. Wilson treats us to a travelogue in space and time covering lands, people and history, and forecasting the future of the millions who live in the Mexico-Colombia-Cuba tropical triangle. The author continually ties his observations to the enlightened self-interest of the United States, and does a good job of developing the theme that the welfare of our neighbors is in a real sense our welfare.

In the conglomeration of races that are the Americas, Mr. Wilson emphasizes properly the predominance of Indians. Their culture, their abilities, are sketched in bold if not always definite strokes, and their desires are in this case not neglected. A brief sketch of the biography and economy of each one of the countries leaves us wanting more, but stimulated by the partial picture. The two chapters on crops tell dramatically the story of the influence on civilization of crop movements. They point to potentialities and sometimes apparently fall into wishful thinking. In these chapters particularly, the book suffers from the lack of a critical blue pencil. However, our past interest has extended mainly to purchasing tropical crops. Few in the United States know these plants intimately. It is perhaps understandable that the author was unable to achieve a high standard of accuracy in his statements. For example, those who know, will be annoyed by references to "ergot root" on page 141. However, the true nature of ergot is indicated on page 147. Those who want to know how derris is propagated, or where allspice came from, and such, should look elsewhere than in Mr. Wilson's yarn.

The discussion of transportation carries the airplane into a role more important than most will predict for it. But the general impression given to the effect that the airplane, and other forms of improved transportation are, and will be, central in determining the advance of agriculture, commerce, and human welfare in these tropical

regions, cannot be denied. The health menace of tropical diseases to Middle America and to us is strongly put, and deserves all the emphasis given.

After reading this fast-moving story, and appreciating its sense of mission, one wishes that Mr. Wilson would apply his writing ability in a further work, the facts of which would be made the responsibility of those who have time to know thoroughly.—Ralph R. Allee.

"ECCE IN DESERTO"

The Gobi Desert. Mildred Cable with Francesca French. 303 pp. Illus. $3.50. 1944. The Macmillan Co., New York.

One does not need to have trekked over the ancient trade routes across China to know that this is a good book and one of great sincerity. Since most of us civilians these days must take our travel vicariously, it is comforting to be reminded that a few books like this one, which attains a high degree of literary excellence as well as factual dignity, are being published at a time when so much opportune but ephemeral and obviously "trumped up" war stuff seems to be the order of the day.

Mildred Cable, a Protestant itinerant English missionary, has lived for more than twenty years in the province of Shansi in North China. Five times, in the course of her work with the China Inland Mission, she traversed the whole length of the Gobi Desert. With her two companions, Eva and Francesca French, she traveled northwestward past the Barrier of the Great Wall and "into the country that lies beyond"—terrifying in its magnitude, awe-inspiring in its antiquity and wisdom. "From Etzingol to Turfan, from Spring of Wine [Suchow] to Chuguchak, we spent long years in following trade-routes, tracing faint caravan tracks, searching out innumerable by-paths and exploring the most hidden oases. . . . The caravan men knew us, carters hailed us as old friends and oases dwellers welcomed us to their homes. . . . Once the spirit of the desert had caught us it lured us on and we became learners in its severe school. The solitudes provoked reflection, the wide space gave us a right sense of proportion and the silences forbade triviality."

Miss Cable's achievement, in setting down her experiences among the peoples and places of the Gobi, is that she has successfully avoided the aridity of the usual travelogue. This, of course, is no facile literary trick, but craftsmanship of the most purposeful and artful kind, even though unselfconscious. Her method may be described as topical, as opposed to chronological or Baedekerian. Each chapter becomes an essay—readable and enjoyable by itself. (The chapter on "The Homes of the Desert" should go in the next English-essay anthology.) Yet all the chapters are bound together by a geographical unity, by the sheer impact of the Gobi. It may be significant too that Miss Cable wrote her book while a guest of the Buddhist priest in the Chapel of Meditation on the Lake of the Crescent Moon, on the edge of the Desert of Lob.

The Gobi is made up of many intangible elements—solitude, austerity, desert-ness. But there is also the tangible life of the Gobi, and it is this life, past and present, that claims this traveler's chief attention—the desert tribes, the oasis dwellers, the caravan men, the roads, the homes, the towns, the Moslems and Buddhists, the priests, the caves and temples, the inns, the fortresses, the palaces and gardens, the various languages, the fauna and flora. All are here, though happily they are not readily separable into their scientific ologies; and out of it all emerges that elusive "thing" which the author endeavors ultimately to convey to her readers—the spirit of the Gobi. And, of course, Miss Cable would be no true lover of the Gobi if she did not at least suggest that there is something mysterious in the charm that the desert holds for those who know it—something perhaps indicative of the urge that drives men onward in their eternal quest to conquer the unknown. As Prof. H. A. Beers once put it:

> The wilderness a secret keeps
>   Upon whose guess I go:
> Eye hath not seen, ear hath not heard;
>   And yet I know, I know . . .

This book is prodigious in its wealth of facts, lore, description, and impression, both of scientific and popular interest. There is much anthropology and geography, some natural history and political history, some

of many things. But for at least one western reader its chief lasting value will be a lesson in humility and a deepening of his respect for the Chinese people and their civilization. Here in the heart of Asia, in what is termed a desert, they have forgotten more perhaps than we occidentals will ever know. They have suffered much; they are bound by traditionalism; yet they are so old and wise. And one cannot help wondering what China may become in our postwar world if freedom for her should really mean freedom.—PAUL H. OEHSER.

FOOD, WAR, AND THE FUTURE

Food, War and the Future. E. Parmalee Prentice. Illus. 164 pp. 1944. $2.50. Harper and Brothers.

THE title points aptly to the major problem of the human race, that of producing enough food so that all may live without hunger and the necessity of struggling with others for a limited food supply.

The first chapter deals with upward trends in population and the need for vastly increased food supplies if the present trends continue. The conditions of want before the 19th century, and the upsurge in production and the well-being of mankind during the 19th century are outlined. The great increase in population in Europe and America during the last century is noted, and the author asks if Europe and America are to share the fate of China, India, and Japan as a result of overpopulation. He points out that:

> There is nothing in Asiatic geography which makes misery unavoidable in that continent, and there is nothing in the geography of Europe and America, nothing in our history, or in the character of our inhabitants, which assures for us the standard of living which we are sometimes told is the birthright of every human being.

The second chapter deals with the abundance that came with freedom of enterprise and improved agricultural practices during the 19th century. Emphasis is also placed on the lack of ability of all but a few to understand that this new condition of plenty would not necessarily continue indefinitely. The author quotes from the *Edinburgh Review*, as follows:

> There is something inexplicable, almost mysterious, in the inability or unwillingness of statesmen, moralists and economists to recognize the truth and inexorable working of the law of population. It almost seems, indeed, as if the refusal of the majority of mankind to recognize this law and its inevitable consequences must be a matter of imposed instinct compelling men to pursue to the end their predestined paths of evolution by ceaseless and ruthless struggle.

Much of the material in this chapter is drawn from other writers who have attempted to analyze trends in population and food production, and their probable effects on the future well-being of the human race. Possibilities for expansion of food production are limited, and the author concludes that:

> Unless numbers can be limited so that America shall not have a population larger than the country can support with the standard of living to which we are accustomed, there can be no hope that we shall be saved from the Asiatic tide of poverty.

The third chapter deals with the possibility of further increase in agricultural production. The author points out that some further expansion of production is possible, but that increases in the supply of food, such as occurred during the 19th century, cannot be anticipated. Future increases owing to improved machinery and methods will be subject to the law of diminishing returns, but all economic additions to the food supply that can be accomplished should be exploited. The author is himself a breeder of dairy cattle and has done considerable thinking and writing in this field, so it is only natural that he should emphasize the part of dairy cattle in increasing food production. As pressure of population becomes greater, man will probably be forced to use less, rather than more dairy and other animal products, but an abundance of animal products is part of the American way of life that we hope to preserve. The author follows his customary vein when he debunks purebred dairy cattle. The term "purebred" is an unfortunate invention, since a degree of genetic purity is implied which cannot exist in practical breeding operations, and the word "purebred," as Mr. Prentice obviously thinks of it, is open to considerable debunking. Also, some of the criticism aimed at purebred cattle associations and at the professors and government workers for their support of his version of the "purebred concept" is justified. The term, "breed" has a rather definite meaning in the minds of most livestock

producers. It is difficult to define, other than as a sub-group within a species, but is usually thought of as a rather uniform group of animals that reproduce with reasonable uniformity. Too frequently, emphasis is placed in uniformity of color and other external characteristics, that have little or no economic importance. But many so-called breeds became so recognized because they had greater economic value for a particular purpose than other animals in an area. Productive characters can be used to define a breed as well as color and shape of horns. Holsteins and Jerseys obviously belong to different populations, on the basis of production of milk and per cent of butter-fat, whether they be labeled breeds or something else. Much of the good germ plasm is now found in the groups of animals commonly referred to as breeds and must be utilized in further genetic improvement, whether that be done by selection within a breed, by crossbreeding, or by some other method. The need of breeding for increased productivity, emphasized in this chapter, is sound. The idea that an animal is good merely because it is registered is obviously open to debunking.

This review is not the place for a discussion of the contributions of animal husbandry workers in federal and state institutions to livestock improvement. Mr. Prentice feels that their efforts, notably in dairy-cattle breeding, have been very disappointing. Many data might be assembled to show the contributions of agricultural workers, even those dealing with dairy-cattle breeding. But such a defense should not be necessary here. Each worker who is conscientiously striving to better the productivity of livestock in America should read this chapter critically and profit by every just criticism that applies to his past efforts.

The fourth chapter is based on the precept that:

> Freedom is the greatest gift which government can bring, and the rarest. It is the source of hope and ambition, of energy and initiative. In America it has brought the abundance for which our country has been remarkable, it makes progress possible and life worth living. If food, and other necessaries of life, are adequate in quantity and variety and if men are free there will be industry. If savings are secure from confiscation and debasement there will be thrift, and an industrious, thrifty people make a prosperous and rich nation.

In the words of Henry Home the author emphasizes that "To every occupation that can give lasting relish, hope and fear are essential," and decries the sudden rise in Great Britain and America of a demand for a protected life. He states "Every nation and every people—if it is to be saved at all—must work out its own salvation. Outside help can provide no permanent rescue from a continuing and ever-growing domestic peril," and "No government is productive. It gets from the people the help it gives to the people, operating always at great expense and with much inefficiency." The author presents his views of how democracy in America should function to best provide a more abundant life, and maintains that the freedoms which the government should protect are freedom of every individual to use his own faculties, eyes and hands and brain, freedom to earn, save and own property and freedom of contract. Many may differ with his views of how government should govern, but there is much to stimulate thought.

In the conclusion, emphasis is placed on the necessity of raising agriculture to a high level of efficiency, keeping prices to consumers low while giving the farmer a generous profit, if our present and future numbers are to be adequately supplied with food.—Ralph W. Phillips.

HAPPY DAYS

Many Happy Days I've Squandered. Arthur Loveridge. 278 pp. Illus. $2.75. 1944. Harper & Brothers, New York and London.

No, dear Author, not "squandered," but days packed with the most profitable activity in which a naturalist can engage, or write about afterwards for the delight and instruction of all who will read! The reviewer took up this entrancing volume in a hammock swung among some of the choicest glories of New England mountain scenery—and scenery, hammock, and self vanished utterly, while his spirit roamed for three enchanted hours with the author in his adventures with animals of the most diverse description. The book opens with the author as an infant and traces his interest in living

things rapidly up to his departure for Egypt, and later to that naturalist's paradise, tropical East Africa. His boyhood experiences with the "skinning" of a partially putrid python, *"un peu passé"*; his encounter with angry but mystified English game-keepers; his bags of frogs and adders; and the accounts of the trials of his long-suffering but thoroughly understanding parents, should be read and studied by all boys (yes, and girls in these modern days) who have a bent for natural history, and especially by the parents of such!

In tropical Africa—and the reader will actually feel himself there no matter where he happened to be when he picked up the book—there are adventures recorded enough to satisfy the most jaded mind. Spitting cobras, horses painted to resemble zebras, the Author in the character of a dispatch rider for the British Army in World War I, birds whose eggs are glued to the inside of an upside-down nest, invasions by the feared Siafu ants (the "terror by night" Loveridge well calls them), baboons and leopards,—and oh, what lions! The accounts of lions are extended—we are grateful to the Author for this—for they are more interesting we think, than insects and reptiles. Never have we read better accounts of lions, their habits, foods, captures, killings (there is a bit too much killing here perhaps), and especially the first-hand reports of the incursions of lions into native villages—never have we read better accounts, we repeat, but all too short. Leopards are well dealt with too—both in the pages and in the "abandoned rubber plantations . . . two miles west of Kilosa." Reader, you will, I wager, give almost anything to be there, "two miles west of Kilosa!" I was there for half an hour this afternoon, and know whereof I speak!

The book is quietly written, for all its adventure. That is, it is written in a pleasing narrative style, in good English—no cheap slang, no straining after unusual effects, no attempts to be "smart," and "different"—a book written decently and in order, as was *Robinson Crusoe* and the *Vicar of Wakefield.* In other words, an easily read book, a pleasing book, an informing book, a provocative book; provoking one, that is, to pack up and go with the Author "two miles west of Kilosa" or anywhere two miles west of anywhere else, so long as it be with Loveridge!

And now, may the reviewer be permitted to say: first, that the book is too short. The Author should have taken a longer time, and written twice as much. It is "touch and go" with many interesting items that really ought to be dealt with more at length. Second, there should be more illustrations. There are five half-pages containing nothing but blank paper—this is unbearably tantalizing! Hasn't the Author a great stack of photographs which a good illustrator could make into cheaply-reproduced, satisfactory line-drawings? Third and last, we note that the jacket flap of the book says "Mr. Loveridge frequently contributes articles to scientific periodicals and magazines devoted to out-door life." He does. What we hope is, that he will contribute to the public store of good books a thick volume every now and then, in the same tenor as the one over which we are now rejoicing.

A glance at the copious and satisfactory index will indicate the scope of the subjects touched upon, which include not only items from the field of biology, but also those from the field of African sociology.

The type is Linotype Baskerville, set on the page just closely enough to make it very easy to read. But oh, Mr. Loveridge and Harper and Brothers, your book is much too short!

The Author, born in Penarth, Glamorganshire, South Wales, is a University of South Wales man, and has occupied the posts of Curator of Natural History in the Museum in Nairobi, Kenya Colony, and Assistant Game Warden of Tanganyika Territory, East Africa. Since 1924 he has been Curator of Reptiles and Amphibians in the Museum of Comparative Zoology, Harvard University. During World War I he enlisted in the East African Mounted Rifles "because it sounded easier than walking." This little straw will indicate which way the wind blows with respect to many delightful touches in the book. Mr. Loveridge, known and respected as a long-headed scientist, is not at all of the long-faced species.—Leon Augustus Hausman.

COMMENTS AND CRITICISMS

The Gracious Touch

We are obliged to Mr. James Paul Stoakes of Huntington, W. Va., for letting us know, through the medium of a letter to THE SCIENTIFIC MONTHLY, about Don Guilermo Bonitto. . . . Altogether Don Guilermo strikes us as the perfect weatherman, and if we had him, or someone like him, to do our forecasting in Washington, it would make even this climate-almost tolerable.—From an editorial in *The Washington Post*, August 15, 1944.

But something *has* been done about the weather in Washington. See "Moonlight and Roses," *The Readers' Digest*, October, 1944.—EDS.

Philosophy and the Supernatural

The simultaneous publication of Carlson's article "Science and the Supernatural" and Bergmann's "An Empiricist's System of the Sciences" in the August '44 issue was thought provoking.

While Carlson's excellent article rejects irrefutably the supernatural as a means of knowledge, this rejection does not appear to me to have exhausted the subject. Any phase of human behavior and its motivation deserves the attention of science as a phenomenon of human nature. Why then should we ignore, by rejection, the supernatural? This is a source of human motivation so strong that it perseveres in spite of science, and indeed as Carlson points out, in opposition to it. I do not mean to imply that science shall continue to apply its method to alleged manifestations of the supernatural; for this can lead back only to Carlson's position. I suggest, rather, that by the application of historical and psychological data (for lack of as yet unobtainable mathematical data), the scientist may qualify the supernatural with reference to the other phenomena of human behavior.

It would require very little investigation along this line to reveal that the supernatural is but a vaporous screen concealing behind it the phenomena of philosophy and religion. Now there can be no difficulty in relating religion with the supernatural for the very obvious reason that all religious tenets are premised on the supernatural. But what possible relationship could be found to exist between philosophy and the supernatural? Philosophy has often paid tribute to science. Was it not indeed the parent of science? However that may be, I may certainly be allowed to declare that all three, religion, philosophy and science are rooted commonly in man's earliest efforts at orientation. Furthermore, it is a more or less unchallenged truism that with the passage of centuries, each of these has gone its separate way. While granting the truth of this for science, I should like to contend that it is not true for religion and philosophy. Specifically, the contention is that philosophy is still tainted with a fundamentally religious concept.

Consider, for example, Bergmann's application of empiricism to a system of science. (It may be granted, I think, that empiricism, for the scientific mind, is the most acceptable brand of philosophic thought.) Beginning from the position of "common sense," Bergman states ". . . With respect to the physical sciences the problem now stands as follows: How can our narrow criterion, according to which all the scientist verifies are simple statements about the positions of pointers and the shapes of instruments, be reconciled with the obvious fact that physicists very confidently and successfully use such abstract things as 'electrical field' and 'elasticity coefficient' and such theoretical conceptions as 'atom' . . . which nobody ever expects to see or touch like physical things . . . ."

This statement, from the philosophical viewpoint, poses a perfectly valid epistemological problem. Yet to a scientist unfamiliar with the dignity bestowed upon it by age, this question must appear naive, if not obstructive. The scientist, unless he consults the works of scientific psychologists, will restate the question for himself thus: How can I know about anything that I cannot reach directly with my five senses? He will reply immediately with the declaration that because he *does* know about things outside the reach of his senses, he *can* know about them. Furthermore, he will assume the existence of an organic relationship between his senses and his thought processes and will set about finding proof for his assumption. In doing so, he will be well within the precincts permitted by the discipline of science.

Now, when a question is asked, it is because a questionable situation exists to ask about. What, then, is the questionable situation existing in the physical sciences which prompted Bergmann's question? Clearly there is none, since the abstracts used by the scientists are used "confidently and successfully." For lack of any other reason, it may be assumed that Bergmann's question is rhetorical and was posed only for the purpose of breaking down the methodological structure of science the better to study its components. From this process, the concept of "operationism" is seen to emerge. By this, it is understood, that in the formulation of any scientific law, the scientist must have observed in operation every component of the phenomenon, regardless of the degree of divergence of its manifestations. Stated simply, and reduced to its essence, this means that the components of a phenomenon must be given their validity via the senses before they can be

formulated into scientific law. Bergmann is now back at his starting point.

But if he is to maintain his philosophic position, Bergmann cannot stop at this point. He must ask again the same question, this time with reference to operationism. He must again create and, if possible, resolve the cleavage between sensory observations of operations and the thought processes they engender. Once stated along this line, the consistent philosopher has no choice but to continue ad infinitum.

This last is true for Bergmann and his contemporaries in philosophy because they are modern philosophers under the influence of modern science and are, therefore, too sophisticated to resort to the tricks or expedients of their ancient predecessors. These, untroubled by modern psychological science, happily resolved this dualism by submerging its parts into a single whole, naming the parts as attributes of the whole. Despite the fact that this whole has been variously named throughout the history of philosophy, the dualism which it embraces, remains the same. What else can this be but the ancient dualism of body and soul? That it is still a living premise for philosophy today is evidenced by the fact that epistomological problems have not yet given way to the science of psychology.

It is on the basis of this persisting dualism that philosophy may be charged today with addiction to the supernatural. For inherent in this dualism is the concept that thought, or consciousness generally, is a thing apart from the material world. Lacking a world created by scientific investigation, what remains is but a world of the imagination.

To be sure, it is hardly conceivable that Bergmann and his fellow empiricists are consciously searching in the realms of the supernatural for an answer to their problems in epistomology. Yet as long as philosophy continues to pose these problems, it must continue to stand accused, at least, of refusing the answers of science, and by corollary, to be searching for them elsewhere.

It occurs to me, furthermore, that this dualism is the source of a basic contradiction between philosophy and science; a contradiction which must make of the philosophy of science mere sterile speculation. For the moment the means of knowledge employed by science are opened, by philosophy, to question, the validity of science is at once shaken. If, on the one hand, the answers of philosophy are affirmative, science is again valid and the philosopher must in all conscience abandon his position for that of the scientist's. If, on the other hand, the scientific means of knowledge are negated, philosophy collapses together with science into an emphemeral world of mystery, or its by-product, the supernatural.

The great role played by philosophy in the launching of scientific investigation cannot be denied. I feel, however, that philosophy has outlived its usefulness to man's efforts at orientation. More, there is good evidence to believe that philosophy, particularly that of the Germans, is being used for evil ends. Let it then be retired with its greatness and dignity unmarred: Or better, let it be the object of study as a manifestation of man's behavior. Within this "frame of reference," it may still yield much in terms of man's self-understanding.—ANNA ROSENBERG.

The Older Worker

I like the conclusions you [A. J. Carlson] drew in the article on "The Older Worker." Since March, 1942, I have been doing some work for The National War Labor Board, and I have become keenly interested in labor problems as the result of my contacts with labor and industrial management. Since my return from the West Indies, I have had an opportunity to try out your conclusions on one labor organization—a local of the Industrial Union of Marine and Shipbuilders Workers of America. The officers of the Union with whom I talked pointed out the difficulty of inducing older employees to accept a reduction in pay when their utility was impaired by age, but they granted the psychological soundness of the proposal. They reminded me, however, that serious thought might have to be given to the younger worker; and that Social Security was designed to take the old worker out of circulation so as to provide a place for the youngsters. Apparently they anticipate the continuing problem of unemployment.

Among my extra-curricular activities is the management of a hosiery company whose workers belong to the American Federation of Hosiery Workers. This organization makes provision for reduced salaries for the older workers, and we actually have in one of our mills two women who are receiving less than the minimum wage for the job performed, though more than would compensate them for the work which they perform. We apply the privilege of placing people in the group of sub-standard workers very cautiously, and thus far we have received Union endorsement and backing whenever we have taken this step. It is the humane and sensible thing to do.

I have written you these facts because I thought you would be interested to know that at least one of your readers has been interested enough in the application of your conclusions to test them out in a practical way. Too often scientific results are not given immediate application, and their author may not learn the reception which his ideas receive.—HOWARD A. MEYERHOFF.